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REFINER
AND NATURAL GASOLINE MANUFACTURER

JANUARY, 1939
Vol. 18, No. 1

A Gulf Publishing Company Publication
EDITED MONTHLY AT HOUSTON, TEXAS

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GEORGE REID
Editor

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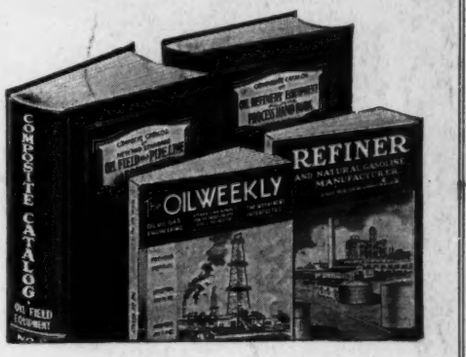

SPECIALIZED OIL JOURNALS

Published by

THE GULF PUBLISHING COMPANY

OFFICE OF PUBLICATION
3301 Buffalo Drive, Houston, Texas

R. L. DUDLEY, *President*
A. L. BURNS, *General Manager*
S. W. ROBINSON, *Editorial Director*
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CHICAGO: 332 S. Michigan Avenue, H. G. Fitzpatrick, Manager.

LOS ANGELES: 425 W. W. Wilson Building, Huntington Park, California, Jay Curts, Jr., Manager.

TULSA: 1513 Hunt Building, J. F. Carter, Jr., Manager.

FT. WORTH: 203 W. T. Waggoner Building, H. H. King, Manager.

Single copies 20 cents. Domestic subscription price $1.00 a year. Canada and Foreign subscription price $2.00 a year. Entered as second class matter June 16, 1923, at the post office at Houston, Texas under act of March 3, 1879. Advertising rates on application. Copyrighted 1939 by The Gulf Publishing Company.

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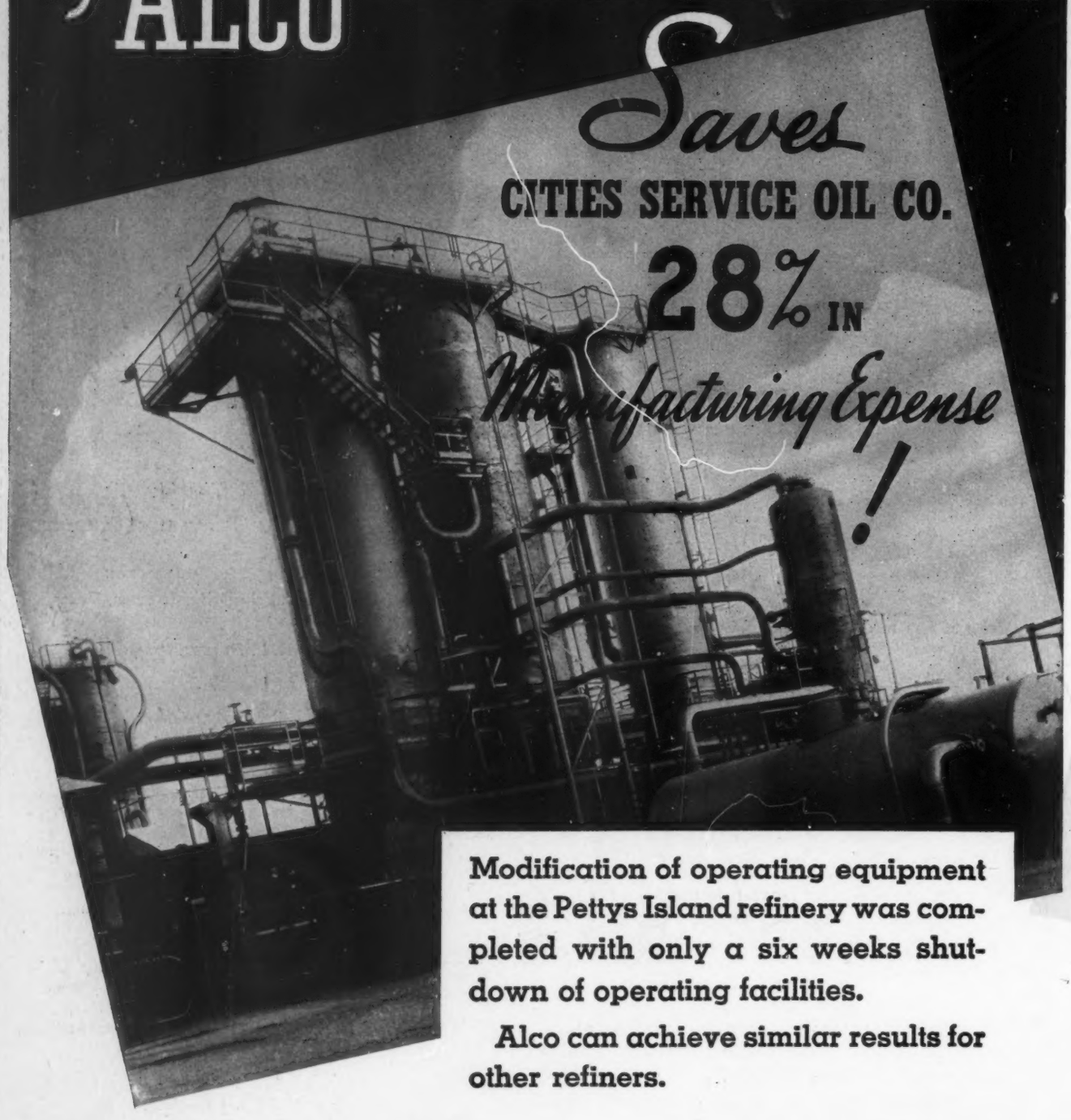

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Typical installation of a large capacity thermal polymerization plant.

GEORGE F. FITZGERALD

Progress in Refinery Technology

THE petroleum industry in 1938 continued its trend toward manufacturing as opposed to simple "refining." Antiquated equipment is being replaced by completely engineered units and obsolete processes are being discarded. Crude oil is more and more being recognized as the raw material for the production not only of superior fuels and lubricants but also for a rapidly increasing list of organic chemicals. Turner and Rubey report (See REFINER, September, 1938, p. 423) that mixtures of hydrocarbon gases are being separated commercially into 99-100 percent pure propane, iso-butane, iso-pentane, and normal pentane. With these pure gases as raw material the manufacture of a wide range of derivatives is being developed. In volume this business means little at present but the trend it indicates is worthy of careful study. The perfection of superfractionating methods and equipment capable of producing material of such purity is important to the refinery of today and indispensable in the refinery of the future.

The development of iso-octane from a knock-test standard to a tank-car commodity is well known but it is only one example of what may be accomplished by applying chemical engineering principles. The industry is definitely committed to a program of modernization. Refineries have the highest obsolescence rates in all industry and many companies expect to rebuild almost completely in the next five years. New processes and developments in equipment design are coming along so rapidly that the too conservative refiner is in danger of losing his markets. Increased demands for product improvement and diminishing profit margin stimulate the turn to advanced methods. The possible

savings in money and the obvious improvements in quality permitted by these changes make their adoption almost mandatory.

The refinery of tomorrow will turn out products of a highly specialized nature. According to current estimates over $200,000,000 will be spent for plant improvements in the coming year. Processes of manufacture are no longer rule-of-thumb but are based on the results of years of research. The problem facing the refiner is the selection of those best suited to his own market.

Construction figures for the country as a whole indicate acceptance of the need for modernizing. Refinery construction on the Gulf Coast in 1938 was the greatest ever, primarily because of the demand for units which will produce higher-octane gasoline. Prominent among these are six combination cracking units now under construction, five polymerization plants and at least one $1,000,000 hydrogenation unit for the manufacture of synthetic aviation fuel. California, second only to Texas as a refining state, has been very active. One plant enlargement project alone cost $5,000,000. This included two combination topping and cracking units of 30,000 barrels capacity each and a catalytic polymerization unit to handle 6,000,000 cubic feet of gas daily. Installations at other plants include a 14,000-barrel combination unit, 18,000-barrel crude distillation and a 14,000-barrel benzol-acetone unit.

FOREIGN CONSTRUCTION

The world situation, despite war scares, points toward increased construction activity. The general trend is to expand and improve existing facilities. This applies particularly to plants located close to their crude supplies. Contrary to this trend, the number of small refineries is increasing. United States supremacy in refining capacity is threatened by foreign construction which will equal or exceed domestic enlargements. This change is emphazied by the fact that the three largest refineries in the world are outside this country.

The Turner Valley crude development in western Canada has stimulated refinery construction there with about 10,000 barrels per day of new capacity under way or planned. A new high in completely automatic operation is achieved by a 12,000-barrel combination crude topping and two-stage cracking and treating plant recently put into service at Halifax. All automatic instrumentation is recorded in one central control room thus permitting speedy check-up on all operations.

Modernization in the West Indies and South America is increasingly active with projected expansion in Mexico delayed because contractors are reluctant to accept a "barter" arrangement of oil in exchange for needed equipment. Germany and Italy are developing every possible source of substitute motor fuel and France is adding large-scale combination, reforming, and re-distillation units. Soviet Russia is following the previously mentioned trend by planning refinery construction near its new eastern crude fields.

CRACKING

Cracking continues to be the most important single feature of refining practice. It is responsible for a vast amount of research which has yielded big dividends in direct savings as well as in conservation of crude. Many authorities feel that six-year-old "crackers" may be profitably replaced by new units. The higher quality and lower costs return a saving to the refiner. The projected construction for 1939 includes impressive catalytic and thermal installations of which many will be combined with primary distillation.

The most striking feature in recent cracking developments is the official announcement of the Houdry process. Refiners have been extremely curious regarding this process ever since the earliest rumors were heard. Its development has required several years research culminating in 1937-1938 with the production of 7,000,000 gallons of synthetic aviation fuel. The Houdry sponsors are this year spending $35,000,000 for 10 units of 10,000 to 18,000-barrel daily charging capacity. Catalysis by means of activated hydrosilicate of alumina is the outstanding feature of the Houdry processes for cracking, vis-breaking, de-sulfurization and polymerization. Gasoline of 77 to 81 octane and exceptional blending value is said to be obtained from any type crude.

The debate over combination cracking versus separate units is still going on with construction figures pointing strongly toward the former. One authority estimates that combination cracking costs about 20 cents per barrel compared with 26 cents a barrel average for separate units. Cracking operations are being tied in with other processes to increase overall efficiency as witness the utilization of cracking-still gases as charge to catalytic-polymerization units in the Mid-Continent.

In the development of cracking process the beneficial results of cooperation in research are amply demonstrated. Commercial cracking started in 1913 but it was limited to gas oil as charge. By 1920 residuums and crudes were utilized and the process came into international use. Cracked-gasoline production in 1936 exceeded that of straight run and the 1938 figures are: Straight run 44.7 percent, cracked 48.6 percent, natural gasoline 6.7 percent. The achievements indicated above were made possible by a far sighted policy of collaboration. The results of fundamental research are currently made available to the entire industry by technical publication. The exchange of cracking licenses has prevented a great amount of litigation and delay. The benefits to the industry and the public in reduced costs, improved quality and conservation of raw material is beyond measuring.

HYDROGENATION AND POLYMERIZATION

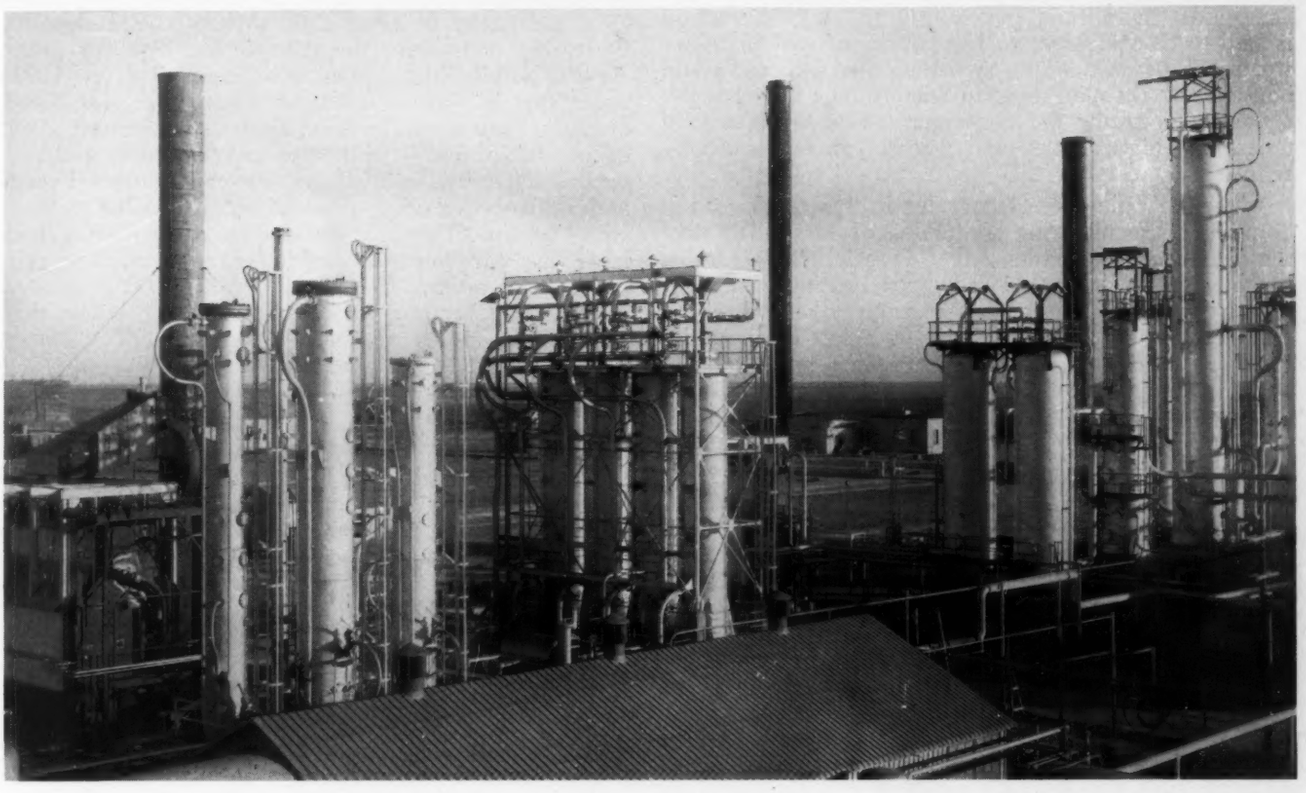
Discussion of cracking inevitably turns to consideration of the complementary processes of hydrogenation and polymerization. Capacity in the latter process today exceeds 100,000,000 cubic feet of refinery gases per day with yields of polymer gasoline exceeding three gallons per 1000 cubic feet of charge. This product has an estimated value to the refiner of 1.5 to 4.5 cents a gallon over regular grades. Its great worth lies in its high blending value which permits corresponding savings in lead fluid. As in cracking processes the refiner may choose between catalytic and thermal methods. The latter gives better yields but the catalytic process involves lower installation and operating costs. Six months ago the small catalytic polymerization plant demonstrated its economy and usefulness. Units operating on less than 300,000 cubic feet of unsaturated gases have justified themselves. One installation is said to have paid out in little over a month. This $10,000 unit produces "2600 gallons per day of polymer gasoline having an octane rating of 83 and a blending value of 100. The combination of polymerization with reforming increases the yield of gasoline from Michigan crude by 7 percent." (Ind. & Eng. News, Aug. 10, 1938.) This technical advance makes the process available for a much larger number of refineries. Of great interest to those refiners producing large quantities of propane and

butanes is the commercial polymerization of these gases on a large scale. (See REFINER, September, 1938, p. 425.) Operating at charging rates as high as 10,000 barrels per day, up to 3500 barrels of gasoline are produced by thermal polymerization. Octane of the gasoline is about 77.0 and its blending value is about 87.0.

With an eye to the future when the supply of cracked gases for further synthesis becomes limited, research is being conducted by Burgin and others (See REFINER, October, 1938, p. 495) on the problem of dehydrogenation of the lower paraffins. Propane and the butanes have been experimentally converted into the corresponding olefins. The operation is catalytic and depends upon the use of activated alumina either as the catalyst or as a carrier for the more active types such as chromium, iron or zinc oxide, vandyl sulfate and reduced nickel. The catalytic mass in use is affected by carbon but may be regenerated with air at 600 to 700° C. Catalysts may be regenerated repeatedly with little loss in activity.

Cracking, hydrogenation, polymerization and dehydrogenation all have a common purpose the production of superior motor fuels. Market requirements show a continuing trend toward higher quality. The octane rating of the average gasoline sold in 1928 is estimated at 51. In 1938 the market average was about 71. The trend of compression pressures is still upward, which means that octane values must be further increased. Iso-octane is available in commercial quantities for aviation fuel while the newer catalytic cracking and polymerizing processes give promise of high-octane gasolines with markedly superior blending qualities. To meet future demands base gasolines must also have improved lead susceptability. Research will continue on present methods while processes for isomerization and alkylation of isoparaffins and olefins approach commercial application.

Observant refiners, however, are keeping in mind that the market for high-octane gasoline is at present limited by automotive design. According to Dr. Wilcox (World Petroleum Refinery issue, 1938, p. 63) most of the existing automobiles do not require such high quality fuels only 10 percent of the cars have been designed for 78-octane or higher, 60 percent require 70-octane or less and 30 percent will not knock on 65-octane gasoline." In view of these figures what will be the effect of Ethyl Gasoline Corporation's recent permission to use Q-fluid in third-grade gasoline? This conventional 62-octane fuel can be readily boosted to 67 or better without exceeding the 3 c.c. per gallon maximum permissible. One large marketer has already announced a 67-octane third grade and if this example is widely followed the ignoble "unbranded" gasoline will be competing for nearly 90 percent of the market instead of 30 percent. Blackwood and others state that if greater care were observed in automobile factory assembly actual octane requirements could be decreased while permitting higher compression ratios and efficiency. Much of the effect of high-octane fuel is wasted by failure to obtain uniform mixture distribution to all cylinders.



Cracking and catalytic polymerization installations in Texas Panhandle plant of Shamrock Oil & Gas Corporation.

AVIATION USES

While discussing motor fuels it would be well to take a look at two other enlarging markets. Aviation markets are, of course, strictly limited today but are bound to increase in the future. As air travel grows and with it the total number of planes in service, the suppliers of satisfactory fuels will have a chance to make a profit.

Of more immediate concern to the refiner is the

Diesel fuel situation. The rapid growth of this market is bound to continue. Striking improvements in engine design make Diesel power ideal for a wide range of heavy-duty applications. Their success in the railroad streamliners is conspicuous but the mounting number of trucking installations is even more important from a gallonage standpoint. Cheaper fuel is not the only advantage to the customer. Power efficiency is also favorable since 6 gallons of Diesel oil will accomplish as much work as 10 gallons of gasoline under the same conditions. In railroad switching 1 gallon of Diesel oil is said to be equivalent to 120 pounds of coal. In other words, 75 percent of the switching fuel expense could be saved by changing over to Diesels. The Diesel is not expected to invade the passenger car or airplane field unless the higher costs and weight can be materially reduced.

What the refiner must consider in this connection is how he can regulate his production of fuel oil to meet the demands for cracking stock, Diesel fuel, and burning oil for domestic and industrial heating. The first is a fairly stable factor since recent years have shown that gasoline consumption does not reflect business depressions and even seasonal variations tend to level out. Consumption of Diesel fuel and burning oils, on the contrary, is governed by the seasons and the business outlook. The refiner will look to processes like catalytic cracking which promise to furnish a means of manufacturing adequate supplies of gasoline with or without the concurrent production of fuel oils.

Associated with gasoline is the production of light petroleum gases. The sale of liquefied propane, butane, and propane-butane mixtures has shown a steady growth encouraged by the refiner. With the growing demand for 100-octane aviation fuel these gases take on an enhanced value as charging stock to polymerization and de-hydrogenation plants. There is no fear of immediate shortage of these gases and experts believe there will be a sufficient supply for several years. When necessary this supply can be increased.

Fundamental research in gasoline continues. The work of Rossini who has spent over 10 years isolating and identifying gasoline components, is well known. The A.P.I. is sponsoring a research project at Ohio State University for the preparation of quantities of pure gasoline-type hydrocarbons. Several dozen of these compounds will be used for engine studies to determine which types are best. It is hoped that such research will yield information of value in making synthetic motor fuels.

The gasoline manufacturer is perennially interested in sweetening methods. New and improved production processes give greater yields and better octane value but the old gum and corrosion problem remains. Newer developments promise to treat gasoline catalytically to satisfactory quality. Of increasing importance in this field are those processes employing copper salts. Good results are obtained on both straight-run and cracked distillates. Polysulfides are not formed and the mercaptan sulfur is completely oxidized to harmless disulfides. Copper chloride units are in successful operation in over 78 plants.

Doctor treating is by no means out of the picture. Methods for continuous plumbite treating are being improved particularly in regard to elementary sulfur addition. Of great importance from the economic angle is a centrifugal process for recovering treated distillate from spent doctor solution. As part of the process this spent doctor is regenerated by a specially designed motor-driven unit which does a better job than the conventional heating and air-blowing procedure. Volumetric recoveries of distillate as high as three percent and substantial savings in treating chemicals are realized.

The threat of substitute fuels is ever present in the minds of gasoline makers. Several years ago the hydrogenation of coal was going to put them out of business. Economic factors prevented that, although the process is employed in European countries. The Canadian government only recently decided against hydrogenation as a means of utilizing that country's coal deposits. Operating costs were found to be too high for profit. Egloff, (Ind. Eng. Chem., October, 1938, p. 1091) states that in Europe substitute fuels from coal, wood, alcohols, natural gas and oil shales will furnish about 25 percent of 1939 requirements. War scares and failure of sugar beet crops have, however, caused French and Italian governments to discourage alcohol mixture with gasoline. Domestic production of power alcohol is falling far short of anticipated figures. The only plant in operation has a capacity of 10,000 gallons of ethyl alcohol per day but actual production is less than 5000 gallons when running.

FILTRATION

Discussion and research on bauxite-type filtering media continues. More refiners are becoming interested but many are waiting for more conclusive published data. Hubbell and Ferguson find (See REFINER, November, 1938, p. 541) that bauxite used in filtering cylinder stocks may be revivified to 80 or 85 percent of its original value and that bauxite used on neutrals may be brought back to 55 to 60 percent. So far the greatest advantage held by bauxite is in the filtration of petrolatums and waxes.

SOLVENT METHODS

There is no longer any question about the future of refining methods employing special solvents for extraction, de-asphalting and dewaxing. General acceptance by the industry is shown by the fact that total throughput for these processes is 50 percent greater than two years ago. Research will bring forth new and better solvents and extend their application. There is pressing need for research into the utilization of solvent extracts. Progress in this regard has been slow particularly in reference to extracts from high-grade paraffinic oils. For comparison the various extraction processes will be given in order of installed capacity throughout the world. Furfural rates first with over 31 percent. Next in order are Duo-Sol, Phenol, SO_2-Benzol, and Chlorex. While the last named represents only 8 or 9 percent of the volume of all extraction plants it ranks first in the Pennsylvania field where four of the five extraction plants employ Chlorex. In solvent dewaxing, Benzol-ketone is the favorite, having more installed capacity than all others combined. Percentage ratings give Benzol-ketone 62.7 as against 23.8 for propane its nearest rival.

Improvements in design and construction based on experience with older units have definitely increased the efficiency of new installations. With development in constant progress and in view of construction currently under way or contemplated, 1939 should see a big increase in solvent refining capacity.

SYNTHETIC PRODUCTS

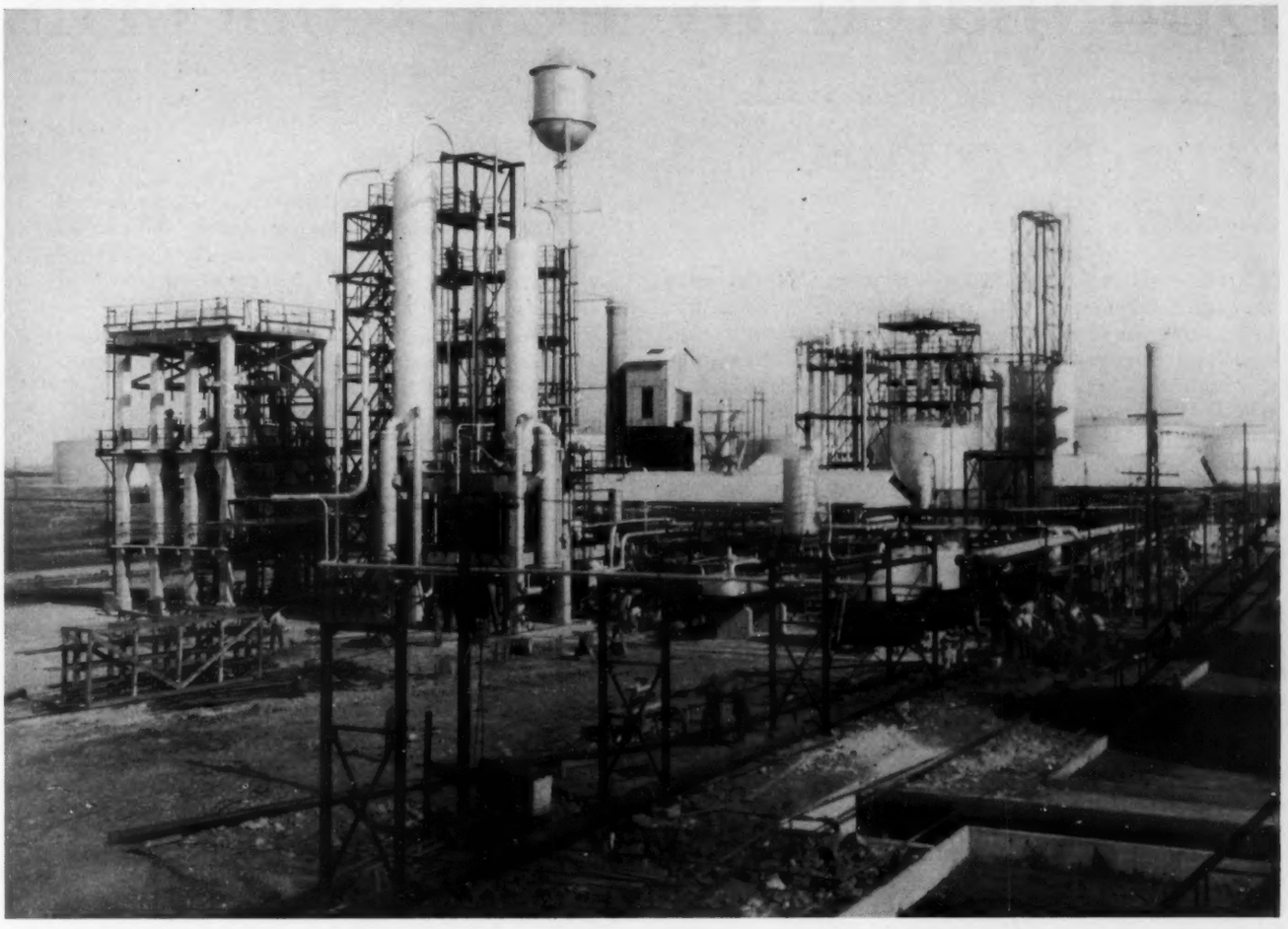
Even a cursory survey of present trends indicates that we are entering the synthetic and catalytic period

of the petroleum industry. High-octane fuels are being produced by a variety of such methods while research is paving the way to more durable lubricants through mixtures of hydrocarbons of unusual properties. Rossini who, as mentioned earlier, has done a great work on gasoline, reported recently to the A.P.I. (See REFINER, November, 1938, p. 557) the results of five years work on lubricant hydrocarbons. His efforts will lead to a knowledge of which types make the best lubes and hence what types must be synthesized for the oils of the future. With the proper background of fundamental science the petroleum industry will be able to furnish lubricants more resistant to the effects of greater speeds and higher temperatures. Such oils will not be highly refined cuts or blends from crude but will be made up of a number of synthetic products each one of which contributes certain properties to the whole. These new lubricants will be exactly compounded to fit the conditions of service they are to meet.

Other factors outside the industry are causing petroleum refiners to study synthetic methods. Leaders in chemical industry are looking more and more to petroleum for raw material. In crude oil they expect to find a large and readily available supply of hydrocarbons which they will transform by methods as yet in their infancy. They will require not only petroleum gases but neutrals and bright stocks, waxes and petrolatums which they will chlorinate, de-hydrogenate, polymerize, isomerize or alkylate into valuable products.

There is now proposed in Texas a $4,000,000 plant which will take raw materials from nearby refineries. Part of the finished products will go back to those same refineries as chemicals for solvent refining.

Solid paraffin wax hydrocarbons are being de-hydrogenated, then oxidized and distilled yielding palmitic and stearic acids suitable for soap manufacture. Waste refinery gases are being converted to acetylene by the electric arc, thence by oxidation and catalysis to vinegar, soap, resins, alcohols, ketones and other products almost without limit. According to Egloff the entire United States rubber supply could be furnished synthetically from butane. Development of these and other processes is dependent on further reduction of manufacturing costs but any curtailment of the natural supply will stimulate their commercial application.



Hydrogenation and polymerization facilities erected recently at Port Arthur by Gulf Refining Company for production of high octane aviation motor fuels.

CONCLUSION

Accurate, detailed correlation of all current petroleum technologic developments is well-nigh impossible. The salient points have been discussed and an attempt has been made to indicate future trends. Unquestionably petroleum refining will become more of a chemical industry applying the established principles of chemical engineering. Whether that means the future production of a wide range of synthetic by-products in the refinery is debatable. It may be found more desirable for the refiner to supply intermediates to other manufacturers who will complete their transformation into the long list of possible derivatives from crude oil.

Refining Capacity Dominated by Few Concerns

GEORGE REID

TWENTY-THREE companies have 81 percent of the total crude-oil-charging capacity and over 87 percent of the cracking facilities in the United States, and they operate 70 percent of the polymerization facilities of the country.

These 23 companies and their subsidiaries have 151 refineries and their operating cracking departments represent 95 percent of the operating cracking capacity of the industry in the United States. The remainder of the refining capacity reported, about 20 percent, is divided among 296 going concerns who operate 328 refineries, of which number 103 plants are equipped with cracking facilities.

The petroleum refining industry, like several other industries, is dominated by a score of large companies, but compared to such other industries as the automotive, public utility and steel, the refining industry is divided among a relatively large number of competitive units.

THE number of petroleum refineries in the United States reached an all-time high in 1935 when 638 plants were reported. Since that time the number has been decreasing until current reports indicate 561 plants, of which number 431 are in operation. During this period, as in previous years, total refining capacity has continued to increase and in 1938 reached 4,373,701 barrels, of which 4,151,276 barrels was operating. This seemingly established a trend which indicates that in the future there will be a decrease in total number of refineries and that there will be bigger plants. Paralleling the growth in refinery capacity has been the increases in cracking capacity in which department there has been a consistent and steady increase during the past 15 years, with present total cracking capacity estimated at 2,547,580 barrels a day. More than half of the gasoline produced today comes from the cracking units of the industry.

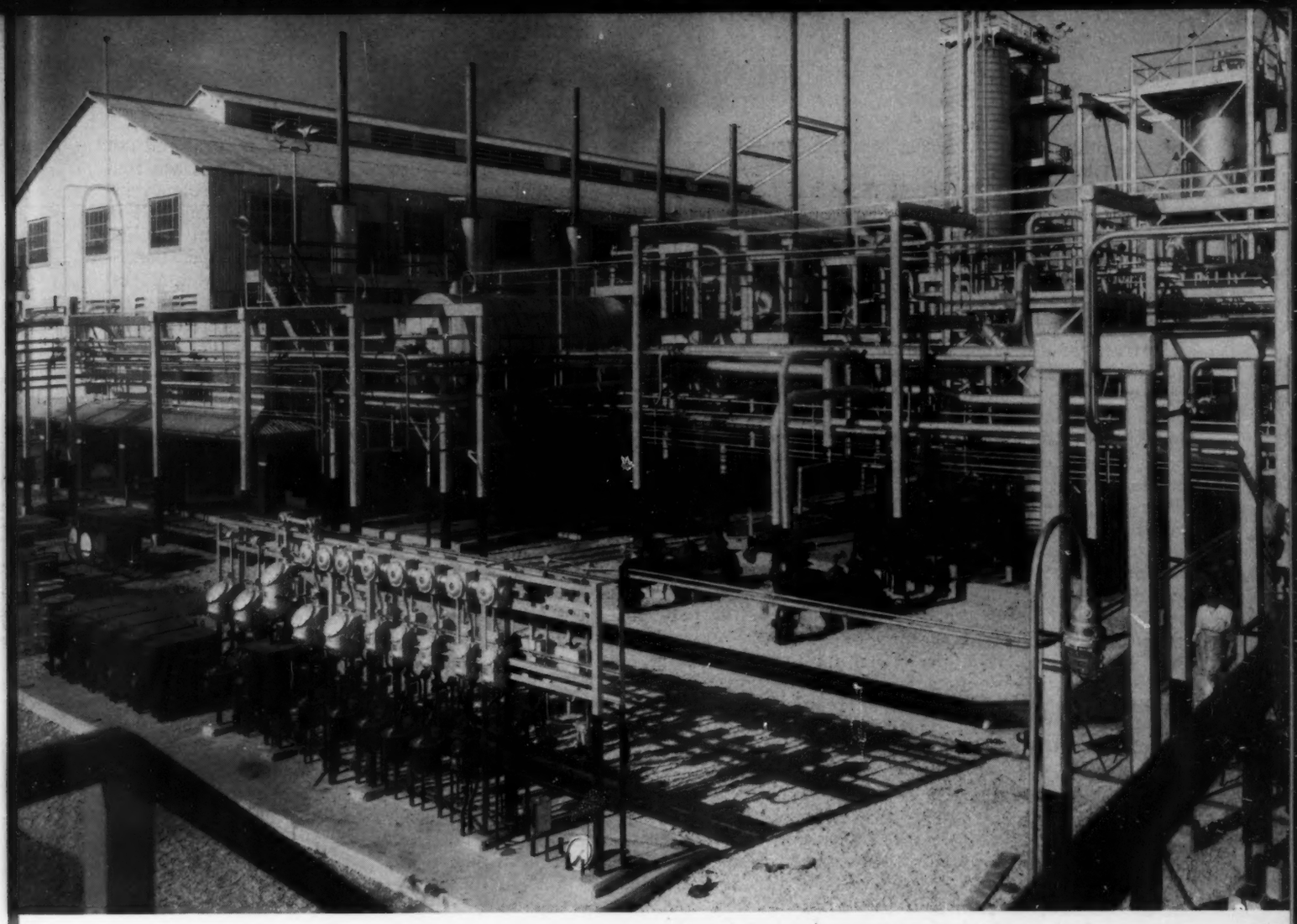
With the trend toward larger refineries and more production of cracked gasoline has come the application and ever widening utilization of such newer processes as catalytic cracking, catalytic polymerization, hydrogenation, and their corollary processes, and the solvent-dewaxing, solvent-extraction and propane-deasphalting and deresining processes used in the production of lubricating oils. For the purpose of bringing down to date information on the types of processes employed by the larger refining organizations in this country, an analysis is presented here which indicates the growth and development of the refining industry as compared to a similar analysis presented in these pages five years ago. This analysis confirms the presence of such trends as previously mentioned and points strikingly to the way the industry is going.

The position and importance of the larger integrated type of companies operating petroleum refining facilities in the United States has been materially strengthened both through mergers and general expansion and additions to facilities during the past five years. In the January issue of THE REFINER, 1933, Vol. 12. No. 1, page 19, an analysis of the refining facilities of 22 leading companies dominating the refining industry in capacity of crude throughput and cracking facilities show that those concerns had 80.7 percent of the total rated capacity and 89.43 percent of the total rated cracking capacity of this country. This group had 89.6 percent of the total operating capacity of the 370 operating plants in this country and 90.86 percent of the reported operating cracking capacity. At that time these 22 companies and their subsidiaries, which totalled 47 companies, had 177 refineries out of the total of 480 plants. This was equivalent to 36.87 percent of the total plants reported and 48.37 percent of the operating plants of that period, operating plants totalling 370 in January, 1933, according to Bureau of Mines reports.

The current status of a similar group of 23 companies indicates a general strengthening of their position during the past five years. During that period the total number of refineries in this country has increased from 480 to 561. Shut-down refineries have increased from 110 to 120. Operating refineries have increased from 370 to 441. Total refining capacity of the industry has shown a gain of 348,701 barrels a day, increasing from 4,025,000 barrels to 4,373,701 barrels daily. Likewise, total operating capacity has increased from 3,625,000 barrels, January 1, 1933, to 1938 total of 4,173,826 barrels, or a gain of 547,826 barrels. All capacity figures in this discussion are taken from Bureau of Mines annual reports covering refineries and cracking operations in the United States.

By comparison with their status five years ago, the improvement in position of the 23 leading integrated companies is indicated by the fact that these concerns with their subsidiaries now totalling but 41 companies because of various mergers, have 81.24 percent of the total refining capacity of the United States, and 85.16 percent of the country's total operating capacity. In the cracking field these important concerns have 87.51 percent of total reported cracking capacity and 94.85 percent of the total operating capacity.

Although these 23 refining organizations have reduced the total number of owned refineries from 177



Installation of propane process for de-asphalting, dewaxing and acid treating in propane solution.

to 151 (a decrease of 26 refining plants) they have increased crude-running capacity for the group from 3,248,650 barrels a day in January, 1933, to 3,554,600 barrels daily at present. Likewise, they have increased their cracking capacity from 1,834,330 barrels daily five years ago, to 2,229,530 barrels a day at the time this analysis was made, November 1, 1938. Present total cracking capacity for the United States is 2,348,050 barrels, while present total rated cracking capacity for the industry is 2,547,580 barrels, with a total of 149,525 barrels cracking capacity reported shut down.

This analysis indicates that these 23 concerns with 151 plants have 26.97 percent of the total operating refineries (441 plants), and 32.24 percent of the total of 561 refineries reported in the most recent survey. There are 120 refineries reported shut down, and total shut down capacity is reported at 199,875. Thus with a decrease in the number of refineries operated by this group of 23 concerns and their subsidiaries, they have at the same time shown important increases in both crude-oil-charging capacity and cracking facilities.

The past five-year period has witnessed the rapid and extensive application of solvent-extraction and solvent-dewaxing processes in the manufacture of lubricating oils, and out of the total of such units reported in this country the group of 23 companies under discussion have installed 50, out of a total of 60 units erected in the United States to date. The companies are using such processes as Edeleanu, Phenol, Bari-Sol, Duo-Sol, Furfural, Benzol-ketone, Chlorex, Nitrobenzene, and the Propane processes for deresining, deasphalting and dewaxing. They have 83.3 percent of the total number of installations at present.

During the same period the thermal and the catalytic polymerization processes have been increasing in importance and in the scope of their application to the problem of producing the anti-knock gasoline of higher-octane ratings from refinery and natural gases. This group of integrated companies has been the pioneering group in the adaption and development of commercial polymerization successfully using the Multi-coil Thermal, the Unitary Thermal and the U.O.P. Catalytic and Shell Catalytic processes to the end that they now have 25 polymerization installations out of a total of 36 units in this country. This is equivalent to 69.4 percent of the units listed at present. In addition to polymerization, two companies in the group of 23 are interested in catalytic cracking, and are installing 8 large units now to cost around $34,000,000. Several installations are operating for production of iso-octane and in the hydrogenation field, 17 of the 23 companies comprising the group being discussed are interested in Hydro Patents Company, and there are now 4 installations of the hydrogenation process operating under Hydro license. Thus in the field of synthesis, these companies, employing various catalytic-polymerization and catalytic-cracking and hydrogenation processes, totalling 29 installations, are leading the industry along those lines which technologists have so long prophesied and speeding the day when petroleum refining will become more of a chemical industry producing perhaps many scores of products along the synthetic or catalytic

route, in addition to larger per-barrel yields of higher-quality motor fuel.

It is well to mark here that there has been no attempt on the part of these larger concerns, and apparently there never will be an attempt, to contrive to hold these important developments to themselves which would be entirely within their rights. Rather, the new and important processes of hydrogenation, polymerization, catalytic cracking, dehydrogenation, cyclization, and others yet to come, are available for all, including the stronger concerns. And they are open for use by any concern financially able to make the installations at sufficiently low royalty rates that they may be profitably operated by those concerns which choose to use them. This was true of cracking, and the later processes mentioned and will no doubt be true of any future developed processes now in the laboratory but not perfected commercially. Further, be it remembered that the licensing companies handling the processes are after all essentially large refining organizations, being controlled by petroleum companies, who by no law of this land are forced to offer to the industry in general the perfection of developments of their own research efforts and organizations. The perfection of the small and inexpensive catalytic-polymerization process now being installed by many of the smaller refining companies possessing cracking facilities, is an example of the desire and the need for making available the advantages of research developments.

Despite the fact that 23 companies and their subsidiaries control such a large percentage of the industry's capacity, there remains the interesting fact that a remainder of 328 refineries in this country are operated by 296 companies. This gives us a total of 335 companies operating refineries in the United States. The capacity of the 328 plants mentioned totals 922,423 barrels a day, and 103 of these refineries are equipped with cracking facilities, leaving a total of 225 refineries in the group of smaller companies which have no cracking plants. Likewise, it is interesting to note that a total of 30 refineries operated by the 23 companies previously under discussion, do not have cracking facilities, giving a total of 255 plants operating in this country (well over half of the operating plants) which have not yet been provided with cracking units—and these plants cannot take advantage of many of the various newly developed processes for synthetic work which were discussed in the foregoing paragraph.

Among the 296 smaller companies operating 328 plants, there is a total of 137,605 barrels daily capacity shut down, which leaves a total of 784,818 barrels a day of operating capacity for the group. In the other group of 23 companies there is 157,010 barrels of shut down capacity reported. This includes not alone entire refineries, but batteries of shell stills and other shut-down distillation facilities not in use for various reasons. If these figures tend to confusion when compared with Bureau of Mines shut-down figures in its Information Circular 7034, attention is called to the fact that for the purpose of this discussion there has been subtracted from the Bureau report 69 companies operating 69 refineries with a total of over 80,000 barrels capacity, which should not be included for the reason that they do not exist.

An interesting facet to this many sided story is that of natural gasoline manufacture. According to latest available reports only 42 of the companies engaged in petroleum refining, out of a total of 335 companies engaged therein, are interested in natural gasoline manufacture. On the other hand there are 176 concerns which are purely or strictly manufacturers of natural and not at all interested in petroleum refining. Thus we find that the manufacturing division of the petroleum industry consists of 511 units or companies engaged in the two branches of manufacture. In natural gasoline manufacture there are about 750 plants in operation.

According to the Bureau of Mines there was a total of 380,955 barrels of shut down refining capacity reported in its 1938 list. Of this, the 23 larger companies reported 157,010 barrels shut down, while the 296 companies with 328 plants reported 223,945 barrels shut down. Another interesting comparison presents itself and that is that during the year 1937 to 1938—there was a total of 283,020 barrels of new capacity built and of this total the 23 companies being studied here erected 224,200 barrels of that new crude charging capacity.

In regard to cracking a similar condition existed. Total cracked gasoline capacity shut down was 78,810 barrels of which the group of 23 concerns reported 60,670 barrels, while the shut down cracked gasoline capacity for the remainder of the industry was but 18,140 barrels. However, in regard to new capacity built during the year, the 23 larger companies erected 63,430 barrels of the total of 86,060 barrels of capacity erected, while the group of smaller concerns erected but 22,630 barrels of cracked gasoline capacity. Attention is called here to the fact that the Bureau of Mines is no longer reporting cracking capacity in figures indicating charging capacity, but only in terms of cracked gasoline capacity secured from cracking operations.

The discussions of cracked gasoline capacity built and crude oil charging capacity built from 1937 to 1938 brings to light something of the expense of attempting to keep this industry up to date. For these two purposes alone the total capacity figure becomes 369,080 barrels of capacity, which at the conservative figure of $200 per barrel of capacity, indicates an expenditure of $73,816,000 for new capacity during the year in question, and this does not include any of the large and small polymerization processes, iso-octane units, hydrogenation processes, solvent-extraction and solvent-dewaxing plants, gasoline-recovery and stabilization systems, solvent recovery, and a wide variety of other construction activities which were taking place during the year. It is estimated that the domestic petroleum refining industry spends around $200,000,000 each year for construction of modern facilities, maintenance and general improvements, and despite this history of continuous annual expenditures of such large amounts the facilities for process work are at best around 40 percent obsolete and in need of replacement.

In regard to the dominating position of the 23 integrated companies analyzed here, the history of their efforts disclosed that not always are they right, and not always do they foresee the influences of economic trends, and not always is a major company refinery an enterprise of permanence. Many of the old timers in this industry and many of the personnel not so old in years can remember their experiences in some of the major company refineries shut down or abandoned during the past few years. A list of abandonments may prove of interest here. Standard Oil Company of New Jersey has stopped operating at Parkersburg, West Virginia. Humble Oil & Refining Company no longer operates at Breckenridge, Chilton and McCamey, Texas. The New Jersey Standard has sold to the Pan American companies (Standard Oil Company [Indiana]) the plants of Mexican Petroleum Company at Baltimore, Maryland; Savannah, Georgia, and Destrahan, Louisi-

GROUP 1 **TABLE 1**

COMPANY	Rated Crude Capacity Bbls./Day	Rated Cracking Capacity Bbls./Day	Type of Cracking Units	Type of Polymerization	Type of Solvent Refining
Standard Oil Company of New Jersey					
Refineries at:					
Baltimore, Maryland	28,000	43,000	Tube & Tank		
Bayonne, Jersey City, and Linden (3 plants)	124,000	180,000	Tube & Tank, Hydrogenation		Phenol
Charleston, South Carolina	5,000	.....	.....	.....	.....
	157,000	223,000			
Subsidiaries—					
Humble Oil & Refining Company					
Refineries at:					
Baytown, Texas	130,000	84,000	Tube & Tank, Cross	Unitary Thermal	1 Propane, 1 Edeleanu, 1 Phenol
Ingleside, Texas	20,000	15,000	Tube & Tank	.....	.....
San Antonio, Texas	5,000	.....	.....	.....	.....
Neches, Texas	5,000	.....	.....	.....	.....
	160,000	99,000			
Colonial Beacon Oil Company, Inc.					
Refinery at:					
Everett, Massachusetts	42,700	24,000	Tube & Tank	.....	.....
Standard Oil Company of Louisiana					
Refinery at:					
Baton Rouge, Louisiana	100,000	50,000	Tube & Tank, Hydrogenation	U.O.P. Catalytic	1 Bari-Sol, 1 Phenol 1 Propane
	142,700	74,000			
GRAND TOTAL—Standard Oil Company, of New Jersey (9 refineries)	459,700	396,000		2 Poly.	7 Solvent
Consolidated Oil Corporation					
Subsidiaries—					
Sinclair Refining Company					
Refineries at:					
East Chicago, Indiana	78,000	47,000	Sinclair	U.O.P. Catalytic	.....
Coffeyville, Kansas	12,000	7,000	Sinclair	.....	.....
Kansas City, Kansas	11,000	7,000	Sinclair	.....	.....
Houston, Texas	55,000	44,000	Sinclair	.....	.....
Fort Worth, Texas	4,000	3,000	Sinclair	.....	.....
Sand Springs, Oklahoma	6,000	3,000	Cross	.....	.....
Marcus Hook, Pennsylvania	40,000	27,000	Sinclair	U.O.P. Catalytic	.....
Wellsville, New York	10,000	6,000	Sinclair	.....	1 Nitrobenzine 1 Benzol-Ketone (Bldg.)
Gladewater, Texas	4,000	.....	.....	.....	.....
Parco, Wyoming	8,000	11,000	Sinclair-Dubbs	.....	.....
	228,000	155,000			
Richfield Oil Corporation					
Refineries at:					
Watson, California	100,000	76,000	Sinclair	U.O.P. Catalytic	.....
Hynes, California	55,000	14,000	Cross	.....	.....
Vinvalve, California	10,000	3,000	Sinclair	.....	.....
	165,000	93,000			
GRAND TOTAL—Consolidated Oil Corporation (13 refineries.)	393,000	248,000		3 Poly.	2 Solvent
Socony-Vacuum Oil Company, Inc.					
Refineries at:					
Brooklyn, New York	19,000	10,000	Houdry, Cross, De Florez	.....	.....
Buffalo, New York	8,500	4,000	Cross, Houdry	.....	.....
Olean, New York	6,500	1,600	Cross	.....	1 Benzol-Ketone 1 Chlorex
Paulsboro, New Jersey	30,500	3,600	Houdry, Tube & Tank	.....	1 Benzol-Ketone 1 Duo-Sol
Providence, Rhode Island	9,000	6,000	Cross	.....	.....
	73,500	25,200			
Subsidiaries—					
Magnolia Petroleum Company					
Refineries at:					
Beaumont, Texas	125,000	50,000	Houdry, Cross, Combination	.....	1 Duo-Sol 1 Benzol-Ketone, 1 Furfural
Luling, Texas	6,800	5,800	Controlled Coil	.....	.....
Corsicana, Texas	4,000	.....	.....	.....	.....
Fort Worth, Texas	5,500	3,000	Cross, Controlled Coil	.....	.....
	141,300	58,800			
General Petroleum Corporation					
Refineries at:					
Vernon, California	28,000	.....	.....	.....	.....
Labec, California	12,000	.....	.....	.....	.....
Torrance, California	52,000	20,000	Combination	.....	.....
	92,000	20,000			
White Eagle Division					
Refineries at:					
Augusta, Kansas	20,000	20,000	Houdry, Controlled Coil	.....	.....
Casper, Wyoming	6,000	5,000	Controlled Coil	.....	.....
	26,000	25,000			
Lubrite Division					
Refinery at:					
East St. Louis, Illinois	7,000	4,600	Own, Houdry	.....	.....
White Star Division					
Refinery at:					
Trenton, Michigan	14,800	3,800	Dubbs, Houdry, Combination	.....	.....
	21,800	8,400			
GRAND TOTAL—Socony-Vacuum Oil Company, Inc. (16 refineries)	354,600	137,400			7 Solvent

Continued on Page 10

TABLE 1—Continued

COMPANY	Rated Crude Capacity Bbls./Day	Rated Cracking Capacity Bbls./Day	Type of Cracking Units	Type of Polymerization	Type of Solvent Refining
The Texas Corporation					
Subsidiaries—					
The Texas Company					
Refineries at:					
Port Arthur, Texas	115,000	96,000	Holmes-Manley, De Florez, Pressure Coke.	U.O.P. Catalytic	1 Furfural, 1 Edeleanu, 1 Benzol-Ketone, 1 Propane Deasphalt
Port Neches, Texas	25,000	.....	.....	.....	.....
Houston, Texas	23,000	2,500	Tube & Tank	.....	.....
Amarillo, Texas	6,000	4,000	Pressure Coke, De Florez	.....	.....
San Antonio, Texas	5,000	5,000	Holmes-Manley	.....	.....
El Paso, Texas	2,000	2,000	Holmes-Manley	.....	.....
West Dallas, Texas	16,000	12,500	Holmes-Manley, De Florez Pressure Coke	.....	.....
West Tulsa, Oklahoma	16,000	15,600	Holmes-Manley, Pressure Coke	.....	.....
Lockport, Illinois	25,000	18,100	Holmes-Manley, Pressure Coke, De Florez.	U.O.P. Catalytic	.....
Shreveport, Louisiana	7,000	.....	.....	.....	.....
Claymont, Delaware	3,500	.....	.....	.....	.....
Pryse, Kentucky	2,500	2,000	Holmes-Manley	.....	.....
Casper, Wyoming	7,000	8,600	Holmes-Manley, Pressure Coke	.....	.....
Calpet, Wyoming	300	.....	.....	.....	.....
Cody, Wyoming	3,000	1,500	Holmes-Manley	.....	.....
Craig, Colorado	1,200	1,200	Holmes-Manley	.....	.....
Sunburst, Montana	5,500	3,500	De Florez	.....	.....
Norfolk, Virginia	2,000	.....	.....	.....	.....
Providence, Rhode Island	2,000	.....	.....	.....	.....
	267,000	172,500			
The Texas Company of California					
Refineries at:					
Coalinga, California	500	.....	.....	.....	.....
Watson, California	37,000	9,000	Holmes-Manley	.....	.....
Fillmore, California	4,000	3,000	Cross	.....	.....
	41,500	12,000			
Indian Refining Company					
Refinery at:					
Lawrenceville, Illinois	16,000	7,000	De Florez	.....	1 Benzol-Ketone 1 Furfural
GRAND TOTAL—The Texas Corporation (23 refineries)	324,500	191,500		2 Poly.	6 Solvent
Standard Oil Company (Indiana)					
Refineries at:					
Wood River, Illinois	90,300	20,000	Holmes-Manley, Combination	.....	1 Chlorex, 1 Propane
Whiting, Indiana	120,700	90,000	Holmes-Manley, Combination	U.O.P. Iso-Octane	1 Propane
Sugar Creek, Missouri	23,700	16,500	Holmes-Manley	.....	.....
Casper, Wyoming	12,600	6,500	Combination	.....	1 Chlorex
Greybull, Wyoming	4,000	1,900	Cross	.....	.....
Neodesha, Kansas	7,500	5,100	Holmes-Manley	.....	.....
	188,800	140,000			
Subsidiaries—					
Pan American Petroleum Corporation					
Refineries at:					
Texas City, Texas	80,000	80,000	Combination	U.O.P. Catalytic	.....
Destrehan, Louisiana	10,000	.....	.....	.....	.....
Savannah, Georgia	4,000	.....	.....	.....	.....
Baltimore, Maryland	8,000	.....	.....	.....	.....
	102,000	80,000			
Utah Oil Refining Company					
Refinery at:					
Salt Lake City, Utah	8,500	7,680	Holmes-Manley	.....	.....
Stanolind Oil & Gas Company					
Refinery at:					
Superior, Louisiana	4,500	2,500	Cross	.....	.....
	13,000	10,180			
GRAND TOTAL—Standard Oil Company (Indiana), (12 refineries)	303,800	230,180		2 Poly.	4 Solvent
Standard Oil Company of California					
Refineries at:					
El Segundo, California	100,000	85,000	Dubbs	.....	.....
Richmond, California	100,000	56,000	Dubbs, Hydrogenation	Hydro. Pat. License.	1 Benzol-Ketone 1 Edeleanu, 1 Phenol, 1 Duo-Sol
Bakersfield, California	25,000	.....	.....	.....	.....
	225,000	141,000			
Subsidiaries—					
Standard Oil Company of Texas					
Refinery at:					
El Paso, Texas	14,000	5,000	Dubbs	.....	.....
Col-Tex Refining Company (62½% Owned)					
Refinery at:					
Colorado, Texas	12,500	3,700	Dubbs	.....	.....
	26,500	8,700			
GRAND TOTAL—Standard Oil Company of California, (5 refineries)	251,500	149,700	1 Poly.		4 Solvent
Gulf Oil Corporation					
Refineries at:					
Staten Island, New York	14,000	.....	.....	.....	.....
Girard Point, Pennsylvania	33,000	26,000	Own	.....	1 Duo-Sol
Fort Worth, Texas	6,000	3,000	Own	.....	.....
Sweetwater, Texas	5,000	4,000	Own	.....	.....
Port Arthur, Texas	134,000	55,000	Own, Hydrogenation	U.O.P. Iso-Octane	1 Benzol-Ketone 1 Furfural
Pittsburgh, Pennsylvania	10,000	6,800	Own	.....	.....
Hoven, Ohio	18,000	4,200	Own	.....	.....
Toledo, Ohio	18,000	16,000	Own	.....	.....
TOTAL—Gulf Oil Corporation, (8 refineries)	238,000	115,000		1 Poly.	3 Solvent

Continued on Page 11

TABLE 1—Continued

COMPANY	Rated Crude Capacity Bbls./Day	Rated Cracking Capacity Bbls./Day	Type of Cracking Units	Type of Polymerization	Type of Solvent Refining
Shell Union Oil Corporation					
Subsidiaries—					
Shell Oil Company of California					
Refineries at:					
Martinez, California	25,000	28,000	Dubbs	Shell Catalytic	1 Furfural 2 Edeleanu
Watson and Dominguez, California	36,000	54,000	Dubbs		1 Edeleanu
Coalinga, California	4,700	.....	.....	.....	.....
	65,000	82,000			
Shell Petroleum Corporation					
Refineries at:					
Wood River, Illinois	43,000	29,500	Dubbs	Shell Catalytic	1 Propane Deasphalt 1 Duo-Sol
East Chicago, Indiana	30,000	21,000	Dubbs	U.O.P. Catalytic	.....
Norco, Louisiana	21,000	14,000	Dubbs	Shell Catalytic	.....
Houston, Texas	80,000	52,000	Dubbs	Shell Catalytic	.....
	174,000	116,500			
GRAND TOTAL—Shell Union Oil Corporation, (7 refineries)	239,000	198,500		5 Poly.	6 Solvent

GROUP 2

TABLE 2

COMPANY	Rated Crude Capacity Bbls./Day	Rated Cracking Capacity Bbls./Day	Type of Cracking Units	Type of Polymerization	Type of Solvent Refining
Tide Water Associated Oil Company					
Refineries at:					
Bayonne, New Jersey	55,000	21,000	Tube & Tank	.....	1 Benzol-Ketone 1 Edeleanu
Drumright, Oklahoma	12,000	7,000	Tube & Tank	.....	.....
Avon, California	60,000	28,000	Combination, Tube & Tank	Multi-Coil	1 Edeleanu
Watson, California	12,000	7,500	Combination	.....	.....
TOTAL—Tide Water Associated Oil Company, (4 refineries)	139,000	63,500		1 Poly.	3 Solvent
The Pure Oil Company					
Refineries at:					
Heath, Ohio	16,000	8,000	Combination, Cross, Gyro	.....	.....
Toledo, Ohio	23,500	13,000	Combination, Gyro	.....	.....
Midland, Michigan	3,000	.....	.....	.....	.....
Muskogee, Oklahoma	9,000	6,000	Combination, Cross	.....	.....
Nederland, Texas	60,000	49,000	Combination, Cross, Gyro	.....	.....
Cabin Creek, West Virginia	4,000	2,500	Gyro	.....	.....
TOTAL—Pure Oil Company, (6 refineries)	115,500	90,500			
Cities Service Oil Company					
Refineries at:					
Okmulgee, Oklahoma	4,000	1,200	Cities Service	.....	.....
Ponca City, Oklahoma	12,000	4,500	Dubbs	.....	.....
East Chicago, Indiana	25,000	15,000	Cities Service	Multi-Coil	.....
East Braintree, Massachusetts	20,000	8,000	Cities Service	.....	.....
Pettys Island, New Jersey	11,500	7,000	Cities Service	.....	.....
Titusville, Pennsylvania	3,000	.....	.....	.....	.....
	75,500	35,700			
Subsidiaries—					
Arkansas Fuel Oil Company					
Refinery at:					
Shreveport, Louisiana	25,000	15,000	Tube & Tank	Multi-Coil (Bldg.)	.....
Cities Service Asphalt Products Co.					
Refinery at:					
Warners, New Jersey	12,000	.....	.....	.....	.....
	37,000	15,000			
GRAND TOTAL—Cities Service Oil Company, (8 refineries)	112,500	50,700		2 Poly.	
Atlantic Refining Company					
Refineries at:					
Philadelphia, Pennsylvania	89,000	32,000	Cross, De Florez, Combination	Unitary Thermal	1 Nitrobenzene 1 Benzol-Ketone
Atreco, Texas	18,000	20,000	Combination	Unitary Thermal	.....
TOTAL—Atlantic Refining Company, (2 refineries)	107,000	52,000		2 Poly.	2 Solvent
Union Oil Company of California					
Refineries at:					
Avila, California	10,000	.....	.....	.....	.....
Maltha, California	5,000	.....	.....	.....	.....
Santa Paula, California	1,200	.....	.....	.....	.....
Oleum, California	32,000	12,000	Combination	.....	1 Propane Deasphalt 1 Edeleanu
Wilmington, California	58,000	13,200	Cross	.....	1 Edeleanu
TOTAL—Union Oil Company of California, (5 refineries)	106,200	25,200			3 Solvent

GROUP 3 **TABLE 3**

COMPANY	Rated Crude Capacity Bbls./Day	Rated Cracking Capacity Bbls./Day	Type of Cracking Units	Type of Polymerization	Type of Solvent Refining
Sun Oil Company					
Refineries at:					
Toledo, Ohio	14,000	10,000	Own, Houdry		
Yale, Oklahoma	5,000	.....	.....	.....	.....
Marcus Hook, Pennsylvania	70,000	65,000	Own, Houdry	.....	1 Sun-Alco, Propane
TOTAL—Sun Oil Company, (3 refineries)	89,000	75,000			1 Solvent
Phillips Petroleum Company					
Refineries at:					
Kansas City, Kansas	23,000	11,000	Dubbs	Unitary Thermal	.....
Okmulgee, Oklahoma	6,000	3,000	Dubbs	.....	.....
Borger, Texas	35,000	48,000	Own	Unitary Thermal	.....
Judkins Point, near Odessa, Texas	.....	.....	.....	Unitary Thermal*	.....
TOTAL—Phillips Petroleum Company, (3 refineries), (1 Poly. Plant)	64,000	62,000		3 Poly.	
Standard Oil Company of Ohio					
Refineries at:					
Cleveland, Ohio	21,000	12,000	Tube & Tank	.....	.....
Toledo, Ohio	14,000	14,000	Tube & Tank	.....	.....
Lima, Ohio	7,500	6,000	Cross-Solar	.....	.....
Latonia, Kentucky	8,000	5,000	Tube & Tank	.....	.....
TOTAL—Standard Oil Company of Ohio, (4 refineries)	50,500	37,000			
Continental Oil Company					
Refineries at:					
Denver, Colorado	1,850	1,000	Cross	.....	.....
Artesia, New Mexico	1,500	650	Cross	.....	.....
Albuquerque, New Mexico	650	.....	.....	.....	.....
Farmington, New Mexico	750	.....	.....	.....	.....
Lewiston, Montana	1,250	.....	.....	.....	.....
Glenrock, Wyoming	2,800	1,800	Cross	.....	.....
Wichita Falls, Texas	4,000	2,200	Cross	.....	.....
Ponca City, Oklahoma	26,000	12,250	Cross-Dubbs	.....	1 Bari-Sol
Baltimore, Maryland	7,500	3,500	Cross	.....	.....
TOTAL—Continental Oil Company, (9 refineries)	45,300	21,400			1 Solvent
Mid-Continent Petroleum Corporation					
Refinery at:					
West Tulsa, Oklahoma	40,000	20,000	Own-Dubbs	.....	1 Chlorex (Propane proposed)
TOTAL—Mid-Continent Petroleum Corporation, (1 refinery)	40,000	20,000			1 Solvent
Globe Oil & Refining Company					
Refineries at:					
Lemont, Illinois	16,500	6,000	Winkler-Koch	.....	.....
McPherson, Kansas	12,000	6,000	Winkler-Koch	.....	.....
TOTAL—Globe Oil & Refining Company, (2 refineries)	28,500	12,000			
Lion Oil Refining Company					
Refinery at:					
El Dorado, Arkansas	16,000	5,000	Own	.....	.....
Stock Control of **Atlas Pipe Line Company**					
Refinery at:					
Shreveport, Louisiana	10,000	6,000	Gyro	Multi-Coil	.....
TOTAL—Lion Oil Refining Company, (2 refineries)	26,000	11,000		1 Poly.	
Skelly Oil Company					
Refinery at:					
El Dorado, Kansas	23,000	15,000	Winkler-Koch	.....	.....
TOTAL—Skelly Oil Company, (1 refinery)	23,000	15,000			
Ohio Oil Company					
Refineries at:					
Lovell, Wyoming	2,500	.....	.....	.....	.....
Robinson, Illinois	10,000	12,000	Holmes-Manley	.....	.....
Bristow, Oklahoma	5,000	1,500	Combination	.....	.....
Fort Worth, Texas	5,000	1,500	Combination	.....	.....
TOTAL—Ohio Oil Company, (4 refineries)	22,500	15,000			
Barnsdall Refining Corporation					
Refineries at:					
Wichita, Kansas	5,000	2,500	Dubbs	.....	.....
Barnsdall, Oklahoma	4,000	2,250	Cross	.....	.....
Corpus Christi, Texas	5,000	5,000	Dubbs	.....	.....
Okmulgee, Oklahoma	7,500 (S. D.)	3,000 (S. D.)	Cross	.....	.....
TOTAL—Barnsdall Refining Corporation, (4 refineries)	21,500	12,750			

* Operated in conjunction with natural gasoline plant.

TABLE 4
Analysis of Refining Facilities of Twenty-Two Leading Manufacturing Companies.

COMPANY	Number of plants	Reported Rated Crude Capacity Bbls./Day	Reported Rated Cracking Capacity Bbls./Day	Type of Cracking Units	Hydrogenation Interests	Number of Polymerization Units	Number of Solvent Units	Type of Solvent Process
Standard Oil Company of New Jersey, with 3 subsidiaries	9	459,700	396,000	Tube and Tank. Cross. Hydrogenation.	Hydro Patents Co. 2 Operating.	1—U.O.P. Catalytic I—Unitary Thermal	7	Edeleanu. Propane. Phenol. Bari-Sol.
Consolidated Oil Corporation, with 2 subsidiaries	13	393,000	248,000	Sinclair. Dubbs. Cross.	Hydro Patents Co.	3—U.O.P. Catalytic	2	Nitrobenzene. Benzol-Ketone.
Socony-Vacuum Oil Company, Inc., with 4 subsidiaries	16	354,600	137,400	Own. Dubbs. Cross. Combination. DeFlorez. Houdry.	Hydro Patents Co.	.....	7	Chlorex. Duo-Sol. Benzol-Ketone. Furfural.
The Texas Company, with 2 subsidiaries	23	324,500	191,500	Holmes-Manley. Pressure-Coke. DeFlorez. Cross. Tube and Tank.	Hydro Patents Co.	2—U.O.P. Catalytic	6	Furfural. Propane. Benzol-Ketone. Edeleanu.
Standard Oil Company (Indiana) with 3 subsidiaries	12	303,800	230,180	Holmes-Manley. Combination. Cross.	Hydro Patents Co.	1—U.O.P. *Iso*octane 1—U.O.P. Catalytic.	4	Propane. Chlorex.
Standard Oil Company of California with 2 subsidiaries	5	251,500	149,700	Dubbs. Hydrogenation.	Hydro Patents Co. 1 Operating.	1—Hydro. Pat. License.	4	Phenol. Duo-Sol. Benzol-Ketone. Edeleanu.
Shell Union Oil Corporation, with 2 subsidiaries	7	239,000	116,500	Dubbs.	Hydro Patents Co.	4—Shell Catalytic. 1—U.O.P. Catalytic.	6	Propane. Duo-Sol. Furfural. Edeleanu.
Gulf Oil Corporation	8	238,000	115,000	Own. Hydrogenation.	Hydro Patents Co. 1 Operating.	1—U.O.P. *Iso*octane.	3	Duo-Sol. Furfural. Benzol-Ketone.
Total—First 8 companies and subsidiaries (24 companies)	93 16.5% of total.	2,564,100 58.62% of total capacity.	1,666,480 65.45% of total capacity.	....	4 Operating.	16 Poly. 44.4% of total.	39 65% of total.	....
Tide Water Associated Oil Company	4	139,000	63,500	Tube and Tank. Combination.	.....	1—Multicoil.	3	Edeleanu. Benzol-Ketone.
Pure Oil Company	6	115,500	90,500	Gyro. Cross. Combination.	Hydro Patents Co.	.....	.....	.....
Cities Service Oil Company, with 2 subsidiaries	8	112,500	50,700	Tube and Tank. Dubbs. Cities Service.	Hydro Patents Co.	2—Multicoil.	.....	.....
Atlantic Refining Company	2	107,000	52,000	Cross. DeFlorez. Combination.	Hydro Patents Co.	2—Unitary Thermal.	2	Benzol-Ketone. Nitrobenzene.
Union Oil Company of California	5	106,200	25,200	Cross. Combination.	Hydro Patents Co.	.....	3	Edeleanu. Propane.
Total—Second 5 companies and subsidiaries (7 companies)	25	580,200	281,900	.....	.....	5—Poly.	8	.....
Total—First and Second Group, 13 companies with subsidiaries (31 companies)	118 21.0% of total.	3,144,300 71.82% of total capacity.	1,948,380 76.44% of total capacity.	....	....	21—Poly. 58.3% of total.	48 80% of total.	....
Sun Oil Company	3	89,000	75,000	Houdry. Own.	.....	.....	1	Sun-Alco Propane.
Phillips Petroleum Company	3	64,000	62,000	Own. Dubbs.	.....	3—Unitary Thermal.	.....	.....
Standard Oil Company of Ohio.	4	50,500	37,000	Tube and Tank. Cross. Solar.	Hydro Patents Co.	.....	.....	.....
Continental Oil Company	9	45,300	21,400	Cross. Dubbs.	Hydro Patents Co.	.....	1	Bari-Sol.
Mid-Continent Petroleum Corporation	1	40,000	20,000	Dubbs-Own.	Hydro Patents Co.	.....	1	(Propane Proposed). Chlorex.
Globe Oil & Refining Company	2	28,500	12,000	Winkler-Koch.	.....	.....	.....	.....
Lion Oil Refining Company, with 1 subsidiary	2	26,000	11,000	Own. Gyro.	.....	1—Multicoil.	.....	.....
Skelly Oil Company	1	23,000	15,000	Winkler-Koch.	Hydro Patents Co.	.....	.....	.....
Ohio Oil Company	4	22,500	15,000	Holmes-Manley. Combination.	.....	.....	.....	.....
Barnsdall Refining Corporation	4	21,500	12,750	Dubbs. Cross.	Hydro Patents Co.	.....	.....	.....
Total—Third Group, 10 companies and subsidiaries (11 companies)	33	410,300	281,150	.....	.....	4—Poly.	3	.....
Grand Total—23 Companies with subsidiaries (41 companies)	151	3,554,600	2,229,530	.....	17 Companies. 4 Units Operating.	25—Poly.	50	.....
Percent of United States Total capacity	26.97%	81.24%	87.51%	.....	.....	69.4%	83.3%	.....
Percent of United States Operating capacity	32.24%	85.16%	94.95%	.....	.....	69.4%	83.3%	.....
United States Totals—Operating capacity	441	4,173,826	2,348,050	.....	.....	.....	.....	.....
United States Totals—Total rated capacity	561	4,373,701	2,547,580	.....	.....	36—Poly.	60 Solvent	.....
Total Shut-Down	120	199,875	149,525	.....	.....	.....	.....	.....

ana. The Sinclair interests in acquiring Richfield Oil Corporation and Rio Grande Oil Company, abandoned refineries at El Paso, Texas; Phoenix, Arizona; Los Angeles, and Bakersfield, California. Sinclair Refining Company abandoned plants at West Tulsa, Blackwell and Muskogee, Oklahoma.

Socony-Vacuum Oil Company mergers and divisions have brought cessation of operations at the Lubrite plant, Wood River, Illinois; Hartles-Maguire at East Chicago, Indiana; Magnolia Petroleum Company at Magpetco and one Magnolia plant at Fort Worth, Texas, and General Petroleum Corporation at Olinda, California. Standard Oil Company (Indiana) has stopped operating at Laramie, Wyoming, and Milwaukee, Michigan. Shell Petroleum Corporation has stopped operating at Arkansas City, Kansas. Tide Water Associated Oil Company has quit at Taft, California. Cities Service Oil Company has dismantled at Gainesville, Texas, and Cushing, Oklahoma. In the East, Atlantic Refining Company has quit operations at Franklin, and Pittsburgh, Pennsylvania, and Brunswick, Georgia. Union Oil Company has dismantled at Brea, California. Pure Oil Company has quit operating at Ardmore, Oklahoma, and Marcus Hook, Pennsylvania. Continental Oil Company has dismantled at Sapulpa, Oklahoma, and stopped operations at Florence, Colorado, and Globe Oil & Refining Company has stopped operating the Blackwell, Oklahoma plant which it had under lease. Barnsdall Refining Company has permanently shut down its Okmulgee refinery, and Ohio Oil Company has abandoned operations at Boynton, Oklahoma, and Del Rio, Texas.

In the foregoing list 14 companies are indicated to have abandoned 34 refineries with total crude charging capacity of 188,550 barrels and total cracking-unit capacity of 79,000 barrels. To offset this decrease in number of plants and charging capacity a number of the companies in the group of 23 concerns have established new plants located in different areas, such as The Atlantic Refining Company's modern installation at Atreco, Texas, and the equally modern refinery of Pan American Refining Corporation at Texas City, Texas. Acquisition of companies by the larger concerns, and the entrance of a couple of growing organizations into the present analysis of concerns having capacity ratings above 20,000 barrels a day, offset the decrease to the end that the present group under discussion have a total of 151 plants in comparison to the total of 177 plants owned by a similar group five years ago. Thus the scene in refinery ownership and company importance is constantly changing, and further, the importance of the stronger and perhaps more aggressive organizations continues to be enhanced.

In the analysis of the facilities owned by the 23 companies which are concerned in this discussion, the companies are arranged in Tables 1, 2 and 3, according to crude oil charging capacity and in that sequence, making three groups such as: First Group, capacity range from 200,000 barrels per day upwards, into which classification 8 companies fall, an increase of 1 company as compared to the survey of January, 1933. The second group consists of companies having reported refinery capacity ranging from 100,000 to 200,000 barrels daily. There are 5 companies in this group, as shown in Table 2, the same number as appeared in the previous survey, but with 2 new names. Due to the merger of Consolidated Oil Corporation (Sinclair) with the Richfield-Rio Grande concerns, Consolidated has become the second largest refining concern in the United States and entered Group 1, as presented in Table 1. Into the place of these two companies have come The Pure Oil Company and The Atlantic Refining Company. The third group as analyzed in Table 3, consists of concerns with less than 100,000 barrels daily capacity, down to 20,000 barrels. New companies entering this group because of enlarged ownerships are Globe Oil & Refining Company with 2 refineries and Lion Oil Refining Company because of its purchase of control of the Atlas Pipe Line Company plant at Shreveport, Louisiana. Both the Pure Oil Company and the Atlantic Refining Company, formerly included in the third grouping, have increased in importance sufficiently to be included in Group 2, Table 2. There are certain other companies operating in this country with ability to operate at 20,000 barrels per day or more, but they are not of the integrated type, have no cracking facilities, and do not occupy important positions in the industry, and are, therefore, not included in the present analysis.

The first group of companies analyzed in Table 1, and consisting of such well-known organizations as Standard Oil Company of New Jersey, Consolidated Oil Corporation, Socony-Vacuum Oil Company, Inc., The Texas Company, Standard Oil Company (Indiana), Standard Oil Company of California, Shell Union Corporation and Gulf Oil Corporation, each with a refining capacity rated above 200,000 barrels per day, operate 93 major refineries, or 16.5 percent of the total in this country.

It is interesting to note that Standard Oil Company of New Jersey with its 3 subsidiaries and 9 refineries has 10.5 percent of the total reported refining capacity, 11.0 percent of total operating refinery capacity; 15.5 percent of total reported cracking capacity and 16.8 percent of reported operating cracking capacity of the industry in this country. Formation of Consolidated Oil Corporation combining the Sinclair and Richfield interests plus extensions in refinery capacity by both concerns, placed that company second in capacity in the domestic industry and displaced Socony-Vacuum Oil Company, Inc., making it now third in the list. The Texas Company, in increasing its over-all capacity from 237,800 barrels in 1933 to 324,500 barrels in 1938, has moved up in the rating from seventh place to fourth. Standard Oil Company (Indiana), during the past five years has increased total capacity from 253,000 barrels to 303,800 barrels, but despite this gain has dropped to fifth place in the ratings. Thus there is a total of five companies in this country operating refining capacity above 300,000 barrels daily.

There has been a distinct tendency on the part of all eight companies in the first group to improve their positions. During the past five years this group has shown an increase in refining capacity from 2,130,300 barrels a day in 1933 to 2,564,100 barrels daily at present, and in the cracking division the increase in capacity has been from 1,205,940 barrels a day five years ago to 1,666,480 barrels present reported capacity. The group of eight companies and subsidiaries operates 93 refineries, or 16.5 percent of the total plants in this country. The refining capacity of this group is 58.62 percent of the total for the country and its cracking capacity is 65.45 percent of the total reported. All companies in this group are interested in Hydro Patents Company, and the four units of this type of hydrogenation now in operation in this country are owned by Standard Oil Company of New Jersey, its subsidiary, Standard Oil Company of Louisiana; Standard Oil Company of California and Gulf Oil Corporation. In the polymerization field the eight companies in Group 1, have 16 installations of all available types, or 44.4 percent of the present total. Likewise, in the solvent-refining field the com-

panies in this group operate 39 installations or 65 percent of the total of the 50 units in this country.

In the second group, Table 2 (capacity ranging from 100,000 to 200,000 barrels) there are five companies including, Tide Water Associated Oil Company, The Pure Oil Company, Cities Service Oil Company, The Atlantic Refining Company and Union Oil Company of California. The Pure Oil Company, through consistent refinery construction recently entered this group for the first time as does The Atlantic Refining Company. The five companies operate 25 refineries with total rated capacity of 580,200 barrels and total reported cracking capacity of 281,900 barrels and they operate 5 polymerization and 8 solvent plants.

Added to the first group, Table 1, to make a total of 13 companies, with subsidiaries totaling 31 companies, with capacity ratings above 100,000 barrels daily, some interesting facts are evidenced.

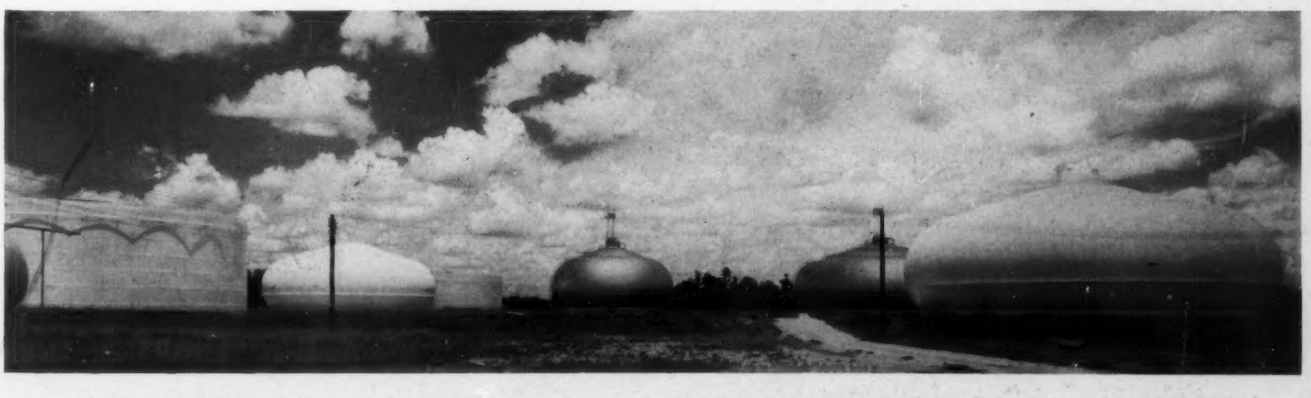
THIRTEEN COMPANIES: 71 PERCENT

Such a group operates 118 refineries which is 21 percent of the total plants in this country. The total crude oil charging capacity is rated at 3,144,300 barrels per day and this figure is 71.82 percent of the country's total. Their aggregate rated cracking capacity is 1,948,380 barrels, which is 76.44 percent of the total for the United States. During the past five years this group of 13 companies has shown a gain in refining capacity of 375,650 barrels and a gain in cracking capacity of 471,900 barrels. They have 21 polymerization installations or 58.3 percent of the total, and 48 solvent refining installations, which is 80 percent of the total for the country.

The third group of companies (Table 3) list consists of 10 concerns which operate 33 refineries with a reported total capacity of 410,300 barrels a day, and a total cracking capacity of 281,150 barrels. They operate 4 polymerization plants and 3 solvent refining installations.

It should be noted that practically all of the properties or manufacturing facilities of these larger concerns are in operation continuously. The 23 companies operating 151 refineries, report but from 6 to 10 of their plants shut down from time to time, of which number 6 plants are apparently permanently closed. The group, however, does report to the Bureau of Mines a total of 157,010 barrels of inoperative capacity which is assumed for the most part to be of the shell-still-distillation type of capacity, and which could be used should conditions necessitate such practice. The figure represents but 4 percent of total capacity for the group as being shut down. Thus the group of 23 companies included in this analysis control or own 41 companies, each of the integrated type, and have 151 refineries—or 26.97 percent of the total number of plants and 32.24 percent of the total number of operating plants in this country. With the aggregate rated capacity of 3,554,600 barrels daily, these important concerns have 81.24 percent of the total reported refining capacity and 85.16 percent of the operating capacity for the country. With 2,229,530 barrels of cracking capacity in this group of 23 concerns, they have 87.51 percent of the total capacity and 94.85 percent of the total operating cracking capacity for the country. The remaining approximately 20 percent of the industry's refining capacity is in the hands of 296 companies, operating 328 refineries, 103 of which are equipped for cracking operations. It is seen, therefore, that a large proportion of these smaller refining companies operate plants of the skimming type, producing straight-run gasoline, possibly kerosene and gas oil and producing much fuel oil. What is true of the dominance of the 23 companies analyzed in this discussion with regard to motor fuel is also true of the production of lubricating oils and greases. But few concerns outside of the integrated companies are engaged in grease manufacture, although there are many smaller refining organizations engaged in the production of lubricating oils especially in the Appalachian refining district and to some extent in Texas and the Mid-Continent areas.

Current announcements relative money to be spent in rehabilitation and extension of oil company properties is indicative of the fact that the leading integrated oil companies expect to continue to strengthen their position and to make ready for such demands as may be put upon them by the automotive and airplane industry and general business recovery. Perhaps to a large extent such expenditures are actually essential in order that they may secure modern efficiencies in plant operation and to be on the profit side. A recent survey of proposed and needed construction work in this country including expenditures for either new construction or modernization of present facilities and general maintenance, repairs and certain types of supplies, indicates that during the year 1939 the industry will spend around $200,000,000. By far the larger proportion of the contemplated work this year will be in the erection of combination cracking units, reforming processes, thermal- and catalytic-polymerization, catalytic-cracking, hydrogenation systems of both low- and high-pressure type, solvent-extraction and solvent-dewaxing installations and new chemical-treating and sweetening processes, with continued activity in natural gasoline plant work and the gas-injection plants for pressure maintenance or repressuring in the fields, which are accompanied by gasoline-extraction systems.



Group of light gasoline storage tanks consisting of Hortonspheroids and Wiggins roofs at the Phillips Petroleum Company plant near Houston, Texas.

Texas Has 30 Percent of Operating Refining Capacity

Ten-Year History of Refining Shows Changing Conditions

GEORGE REID

DURING the past 10 years the total capacity of the petroleum refining industry in the United States has increased 1,000,000 barrels a day. Present indicated total crude capacity is reported at 4,634,171 barrels as compared with 3,608,540 barrels 10 years ago. With regard to actual operating capacity the increase during the decade has been from 3,325,890 barrels to 3,970,196, or a total of slightly over 825,396 barrels daily.

This over-all increase in capacity, however, has not been of a general nature, and in certain of the refining districts no increase has been shown; in others actual losses in capacity or economic importance of the industry has been experienced, while in two areas marked increased capacity and increase in actual plants has taken place. These changes in status or importance of the refining districts affected are attributed to a number of influencing factors; such factors affecting the various districts in greater or lesser degree. All of the refining districts with the exception of the East Coast are located in or adjacent to oil-producing territories to the end that most refining centers or areas are influenced to a large extent by the success or failure of crude-oil exploration efforts. Oil for refining in the East Coast plants has always been imported into the area by pipe line and tanker with the refineries in that territory gauging

Air view of the Port Arthur refineries of The Texas Company and the Gulf Refining Company.

their operations upon local demand in highly concentrated areas as to population and upon export requirements.

The most important gains in importance, capacity, or number and size of plants during the past decade have been experienced in Texas, with particular emphasis on the Texas Gulf Coast region, and the Indiana, Illinois, Kentucky, Michigan refining districts. The area showing the greatest loss in both number of plants and crude charging capacity is Oklahoma, and there has been like experience in declining relative importance in Kansas, the Rocky Mountain and the Appalachian refining district. California during recent years has been managing to hold its position with a leveling-out effect, while Louisiana has shown a slight gain in importance during the past three years.

MOVE TO SEABOARD

The larger refining organizations and a number of the smaller or independent concerns have been for several years establishing refineries at the seaboard ports, chiefly in the Texas Gulf Coast area including the Beaumont-Port Arthur, Houston-Texas City, and the Corpus Christi districts. This trend has brought refining interests into the Gulf Coast chiefly from Oklahoma, Kansas and the Eastern Seaboard. Refiners in the Mid-Continent district, especially in the territory designated as "Group 3," have been maintaining for some time that it is virtually impossible to operate profitably under present conditions of crude-oil prices, freight rates, taxes and prices on finished products. These have been important factors in bringing about the marked decrease in importance of Oklahoma as a refining state. Other factors of course include the appearance of competitive crude oil, such as production from Illinois, and the development of a Michigan refining district following development of that state as an important producing area.

The history of the individual refining states and districts is given in the accompanying Tables 1 to 11, and the graph, Figure 1. A study of these data will indicate the trends in the various districts. In Table 1, the history of the Appalachian district for 10 years is presented and there is indicated a gradual reduction of plants and crude oil capacity. In 10 years the number of plants has decreased from 55 to 38, or a loss of 17 refineries and a decrease in capacity of 17,700 barrels a day. In relation to total refining capacity for the country the district has not been of great importance for many years, but its chief claim to importance lies in the fact that it produces high-quality lubricants, and these refineries, small as they may be in individual capacity rating, represent large investments in a very wide variety of equipment and processes and their technique is constantly improving to secure better efficiencies and improved quality of products.

Arkansas, analyzed in Table 2, continues to remain fairly constant with 6 to 8 plants averaging from 35,000 to 48,000 barrels per day of refining capacity in operation. These are for the greater part located around the important production areas of the state, and it is apparent that their success, failure, or permanence depends to a large extent upon continued exploitation of and discovery of new fields in that state.

California, as shown in Table 3, has averaged ap-

TABLE 1

Table Showing History of Refining in the Appalachian District

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	55	60	116,200	120,380
1930	54	60	130,680	143,560
1931	45	61	135,930	157,810
1932	50	57	151,180	161,930
1933	45	54	149,530	160,280
1934	44	54	154,150	168,750
1935	42	53	163,650	178,650
1936	39	52	152,875	177,525
1937	38	45	142,675	160,975
1938	38	43	136,450	155,300

TABLE 2

Table Showing History of Refining in Arkansas

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	8	10	35,000	37,440
1930	8	9	41,500	47,000
1931	8	9	46,000	47,500
1932	8	9	41,000	46,500
1933	8	9	41,500	44,800
1934	8	9	38,050	43,550
1935	6	9	38,250	48,750
1936	7	10	37,200	47,700
1937	7	8	36,250	41,750
1938	6	9	39,250	48,750

TABLE 3

Table Showing History of Refining in California

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	52	69	841,460	916,460
1930	53	62	888,730	914,780
1931	55	69	871,430	927,180
1932	55	74	822,010	940,760
1933	44	61	783,135	900,735
1934	52	62	755,210	854,710
1935	64	73	759,435	840,635
1936	60	76	799,160	859,110
1937	59	77	798,860	870,110
1938	67	81	818,610	897,160

TABLE 4

Table Showing History of Refining in the East Coast District

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	24	27	588,200	603,200
1930	24	26	605,000	614,000
1931	23	26	614,500	632,500
1932	24	25	619,500	623,500
1933	23	27	563,000	617,000
1934	25	26	609,000	614,000
1935	25	26	613,500	619,500
1936	25	26	617,600	624,100
1937	24	25	665,500	670,500
1938	23	25	595,900	615,700

TABLE 5

Table Showing History of Refining in the Illinois-Indiana-Kentucky District

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	27	31	324,000	336,500
1930	35	38	397,060	413,060
1931	32	39	418,150	455,150
1932	39	46	408,067	420,167
1933	36	46	438,688	450,738
1934	40	50	423,820	440,620
1935	46	56	445,870	463,270
1936	47	57	462,930	483,430
1937	48	58	510,050	522,230
1938	49	63	512,110	570,380

TABLE 6

Table Showing History of Refining in Kansas

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	15	19	126,500	137,500
1930	14	18	130,000	141,500
1931	14	16	141,000	146,000
1932	14	17	140,000	154,120
1933	16	20	150,380	163,505
1934	23	27	160,461	170,761
1935	21	26	163,545	171,045
1936	22	26	174,100	178,750
1937	20	26	172,100	181,200
1938	21	27	160,660	186,850

TABLE 7

Table Showing History of Refining in Louisiana

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	14	17	216,830	226,330
1930	13	14	217,380	237,380
1931	10	13	193,200	226,200
1932	10	14	185,800	224,400
1933	11	16	170,050	209,650
1934	10	17	174,750	211,650
1935	11	19	173,050	205,300
1936	12	19	183,000	217,350
1937	14	17	198,650	216,900
1938	11	14	199,750	212,750

TABLE 8

Table Showing History of Refining in Oklahoma

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	42	54	274,700	303,500
1930	43	52	287,500	308,550
1931	45	59	316,900	349,100
1932	39	53	285,300	326,550
1933	44	59	277,220	324,700
1934	42	60	268,909	315,989
1935	32	58	245,520	309,259
1936	32	50	252,420	289,859
1937	31	39	237,850	260,850
1938	29	39	213,950	256,900

TABLE 9

Table Showing History of Refining in the Rocky Mountain District

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	34	46	130,400	142,150
1930	33	47	144,200	155,900
1931	36	52	150,400	161,870
1932	40	56	145,570	159,936
1933	39	74	80,545	104,552
1934	71	101	81,975	101,368
1935	76	113	84,570	100,692
1936	65	113	86,680	101,773
1937	71	102	97,206	111,861
1938	73	105	102,366	118,476

TABLE 10

Table Showing History of Refining in Texas

YEAR	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
1929	68	90	658,100	767,580
1930	78	91	773,275	807,555
1931	75	98	795,600	860,875
1932	84	124	804,165	935,065
1933	103	151	769,070	914,035
1934	137	190	864,744	1,010,269
1935	110	197	906,859	1,106,299
1936	111	212	961,870	1,155,799
1937	109	183	1,081,775	1,313,955
1938	112	153	1,171,180	1,283,735

TABLE 11

Table Showing History of Refining in Texas Gulf Coast

Year	Number Plants	Operating Capacity	Total Capacity
1929	17	449,000	499,000
1930	16	519,700	528,700
1931	17	530,500	542,000
1932	17	542,000	558,000
1933	18	497,500	516,000
1934	20	536,500	572,000
1935	21	613,000	623,500
1936	25	633,800	651,800
1937	33	767,500	834,000
1938	31	906,500	916,000

proximately 750,000 to 825,000 barrels capacity during the past 8 years, operating an average of 70 to 80 refineries during that period. This area, being classed as an empire within itself, must depend upon its own continuing growth in population and industrial importance for any further increase in importance as a petroleum refining center. Its distribution or marketing area extends from Mexico to Canada and eastward into the Mountain States, such as Idaho, Arizona, Utah, etc., but with its chief demand within the state itself. California has shown repeatedly that price wars do little to increase gasoline and lubricating oil demand or to increase its importance as a refining district. However, the major concerns in this territory continue of necessity to spend millions each year in the modernization of refining facilities in order to operate profitably under the economic conditions peculiar to the district and to secure profits from its exporting enterprises.

The East Coast refining district, as shown in Table 4, has leveled off with 23 to 25 operating plants, but with some recent decline in capacity totaling 69,600 barrels a day. Operating capacity is now reported at 595,000 barrels as against a recent high of 665,500

TABLE 12

Table Showing Relative Importance of Various Refining Districts, 1938

DISTRICT	Operating Capacity	Percentage of United States Total	Total Capacity	Percentage of United States Total
East Coast	595,900	15+	615,700	14+
Appalachian	136,450	3.4	155,300	3.32
Indiana, Illinois, Kentucky, etc.	512,110	12.89	570,380	13+
Oklahoma, Kansas, Missouri, etc.	390,580	9.8+	467,450	10.68
Texas	1,171,180	29.49	1,283,735	29.35
(Texas Gulf Coast)	(906,500)	(22.83)	(916,000)	(20.94)
Louisiana	199,750	5.0	212,750	4.86
Arkansas	39,250	.98	48,750	1.11
Rocky Mountain	102,366	2.5	118,476	2.7
California	818,610	20.6	897,160	20.5
Total	3,970,196	....	4,373,701	....

TABLE 13

Refinery Operations and Capacity in the United States Last 10 Years

DATE	NUMBER PLANTS		Operating Capacity	Total Capacity
	Operating	Total		
January 1, 1929	341	427	3,325,890	3,608,540
January 1, 1930	358	420	3,634,825	3,802,785
January 1, 1931	346	445	3,706,610	3,987,685
January 1, 1932	365	479	3,624,992	4,023,328
January 1, 1933	372	523	3,445,118	3,921,055
January 1, 1934	454	604	3,553,569	3,962,667
January 1, 1935	435	638	3,614,749	4,072,400
January 1, 1936	422	647	3,749,835	4,163,946
January 1, 1937	423	583	3,966,616	4,376,081
January 1, 1938	431	561	4,151,276	4,376,081*
January 1, 1938	431	561	3,970,196	4,634,171†

* Old Basis. † New Basis.

From Bureau of Mines, I. C. 7034. "Petroleum Refineries, Including Cracking Plants in the United States. January 1, 1938," issued August, 1938.

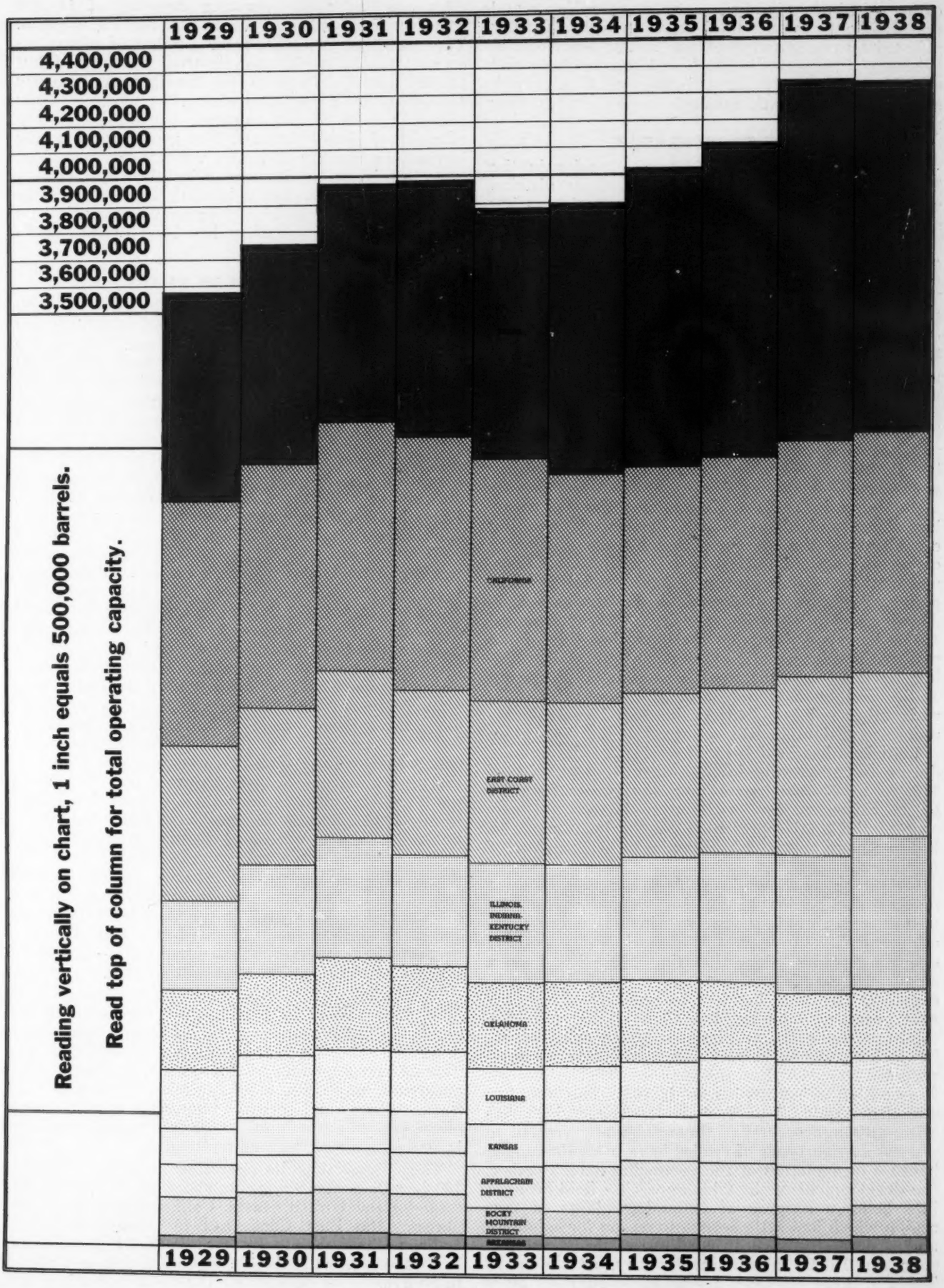

1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
4,400,000
4,300,000
4,200,000
4,100,000
4,000,000
3,900,000
3,800,000
3,700,000
3,600,000
3,500,000
Reading vertically on chart, 1 inch equals 500,000 barrels.
Read top of column for total operating capacity.
CALIFORNIA
EAST COAST DISTRICT
ILLINOIS, INDIANA, KENTUCKY DISTRICT
OKLAHOMA
LOUISIANA
KANSAS
APPALACHIAN DISTRICT
ROCKY MOUNTAIN DISTRICT
ARKANSAS

FIGURE 1

barrels. As previously stated, its crude is imported or brought in by pipe line or tanker from Texas and the Mid-Continent. Its total capacity may be further affected by continuation of the trend toward establishment of refineries in the Gulf Coast territory and continued increases in plants in the Gulf Coast which supply the area with finished products by tanker shipment.

MIDWEST INCREASING

Petroleum refining facilities and capacity in the Illinois - Indiana - Kentucky and Michigan district, which includes Ohio, have been steadily increasing since 1929, as is shown in Table 5. The number of operating plants has increased from 27 to 49 during the past decade, while total plants have increased from 31 to 63. Should the continued development in Illinois Basin make profitable the operation of plants in that field, it is possible that several plants of the smaller type may go in during the next year or so. In addition to increased industrial importance and population growth, the growing refining capacity may be attributed to the development of Michigan as a refining center and increases in refining capacity in Ohio. The large plants owned by the major companies serving this territory have been steadily growing in importance since their establishment many years ago.

As shown in Table 6, Kansas averages 20 operating plants and about 145,000 barrels of operating capacity over the 10-year period. Present operating capacity is around 160,000 barrels with 21 refineries, and total capacity is given as 186,850 barrels with 27 plants. The closing down of Shell Petroleum Corporation's plant at Arkansas City last year removed 16,000 barrels a day from the operating side of the picture. The future of Kansas as an important refining territory depends upon its crude-oil-producing ability, freight rates and finished product prices and, as in other refining districts, improved general economic conditions in this country.

Louisiana has held fairly steady as a refining state during the 10-year period. Its operating capacity of 175,000 to 200,000 barrels per day comes from 10 to 12 refineries, but with approximately 50 percent of the total represented by the large plant at Baton Rouge operated by Standard Oil Company of Louisiana.

Oklahoma, as shown in Table 8, has seen the most marked decline in refining importance during the past 10 years. Its best year was in 1931, when operating capacity totaled 316,900 barrels a day from 45 operating plants. Since that time there has been a steady decrease in both number of refineries and in capacity. The state has lost 18 refineries during recent years, now having but 29 operating out of a total reported of 39, and its present operating capacity is but 213,950 barrels daily. Likewise its total reported capacity has dropped to 256,900 barrels from a high of 349,100 barrels in 1931. The state has sufficient crude-oil production to support its refineries, although several of them originally erected to process certain types of crudes have been abandoned because of depletion of the producing field. Further, the development of the Oklahoma City field brought into being a number of skimming plants in that region which had little economic reason for existence and of necessity have dropped out of the picture.

In the Rocky Mountain territory, as shown in Table 9, there has been a gradual leveling-off since the marked drop in 1933, with slight increases noted in 1938. Note that in 1932 in this district 40 refineries reported total operating capacity of 145,570 barrels, which dropped to 80,545 barrels in 1933. Then again in 1935 the total number of plants increased to 113, with total reported capacity of but 100,692 barrels. In 1938 the leveling-off influence brought about a condition where 73 operating plants out of a total of 105 reported have an operating capacity of 102,366 barrels. The greater part of the increase in number of plants which have come and gone in this district have been installed by concerns misled into belief that skimming type of refinery operations would be highly profitable, for the lists indicate that the mortality has been among skimming plant operators.

BIG GROWTH IN TEXAS

The most remarkable growth in importance, both from the standpoint of refineries and operating and rated capacity, has occurred in Texas. During the past 10 years refining capacity has been practically doubled, with the same situation existing with regard to number of plants in operation. At present the state has 112 plants operating out of a total of 153 reported, and the operating capacity is 1,171,180 barrels daily, with total capacity reported at 1,283,735 barrels. As is shown in Table 12, which presents the relative importance of various refining districts, Texas has 29.49 percent of the operating capacity in the United States and 29.35 percent of the country's total rated capacity. This growth in capacity and in number of operating plants of importance has been a steady increase since 1933 and 1934 when the legion of tea-pot and junk-pile operators were forced out of East Texas. At present the state has 31 refineries in the Gulf Coast district and 122 plants in Inland Texas and the operating capacity of the inland plants is reported at 264,680 barrels a day, with total capacity given as 367,735 barrels. There has not been the marked development in Inland Texas refineries that has occurred in the Gulf Coast area. The Texas Gulf Coast refining district, as analyzed in Table 11, has grown during the past 10 years from 17 plants to 31, and capacity has more than doubled, increasing from 449,000 barrels in 1929 to 906,500 barrels in 1938. During the same period total capacity has increased from 499,000 barrels to 916,000 barrels. Of the present total operating capacity, 859,000 barrels is located in the Houston, Beaumont, Port Arthur district and 57,000 barrels in the Corpus Christi area. Thus the Gulf Coast of Texas has a total of 77.39 percent of the operating total for the state and 71.36 percent of the total capacity of the state.

In relation to the entire United States, the Texas Gulf Coast refining district now represents 22.83 percent of the domestic operating capacity and 20.94 percent of the total rated capacity of this country. The nearest approach to relative importance of this nature for any other single refining district is California where total operating capacity is 20.6 percent of the United States total, and total reported capacity is 20.5 percent of the country's total.

Thus Texas with its operating capacity of 1,171,180 barrels a day represents about 30 percent of the total for the United States, California has about 20 percent, the East Coast has 15 percent, and the Indiana-Illinois-Kentucky, etc., district approximately 13 percent, while the Texas Gulf Coast area alone has virtually 23 percent of the total operating domestic capacity.

Union Oil Company of California at its Oleum refinery recently completed a combination atmospheric-vacuum distillation unit and new cracking facilities.

Pacific Coast Refining Industry Continues Modernizing Work

DURING 1939, California's $2,500,000,000 refining industry will run 200,000,000 barrels of crude oil and produce upwards of 78,000,000 barrels of finished motor fuel. Close to $6,000,000 will be spent on the upkeep of refining and treating facilities now in operation, and a probable $10,000,000 on the erection of new equipment. Around $500,000 will be spent on research and development. Each year finds the refining industry, whether it be on the Pacific Coast or elsewhere, continuing the never-ending search to modernize plants and plant equipment in order to insure more efficient operation and better quality for the products. Concurrent with this search for betterment is the unavoidable demand which obsolescence creates and which must be dealt with.

The modern refinery is an intricate and delicate mechanism requiring constant adjustment, repair or modernization to keep pace with changing trends in manufacturing and marketing. Next year will demand its toll of replacements which will include pressure vessels of all sorts, pumps, heat exchangers, fractionating towers and stills. This constant destruction of fabricated metal by chemically-reactive substances, generated during distillation or cracking, extends to the remotest part of the refinery yard and adds the necessity for the replacement of tubular goods, and large numbers of high-pressure valves, flanges and other fittings. Corrosion and general metallic deterioration are vital problems wherever refining is done and bring to the Pacific Coast industry its share of troubles next year.

It is difficult to sectionalize refining problems to the extent of describing one group of problems as separate and distinct from those encountered in another section of the country, but without overemphasizing any of the Pacific Coast refiners' difficulties

it is safe to say that as he views his 1939 problems he will be impressed by the advent of many things which will more exactly assist his economic analysis of the feasibility of almost any step he might wish to take, whether it be polymerization, cracking, or solvent dewaxing.

A scant three years ago gas losses in refineries, particularly those arising from reforming operations, were annoying and many refiners resigned themselves to the toleration of this wastage. Soon, however, polymerization came along and virtually solved the problem for him. In many instances the problem created by an improvement in refining technique has been solved by the development of a supplementary process which utilizes the very element causing the trouble. Regardless of what the Pacific Coast refiner does about cracking next year, he will be aware that more efficient, or deeper, cracking makes for greater difficulties in the subsequent treating and sweetening of distillates. It is a fact that fundamentally, octane value must be preserved and a definite control exercised over gum formation and polymerization. Some observers are of the opinion that the cold-treating process for distillates which involves a counter-current contact between acid and distillate, and a centrifuging of the distillate may gain western popularity next year. It is reported that another of the large refineries intends to install a unit for treating in this manner.

Richfield Oil Corporation's newly completed refinery at Watson, California.

STUDYING POLYMERIZATION

The application of polymerization is still in its infancy in California. Of the 70 refineries operating in this section at present only 4 have equipment with which to carry out polymerization. In choosing equipment for this process the refiner has three methods to select from: 1) unitary thermal; 2) multiple coils; and 3) catalytic. Of the 4 installations in operation now, 3 are of the catalytic type and the fourth of the Multicoil.

At Norwalk, California, Wilshire Oil & Refining Company has in operation a catalytic unit with a capacity of 6,000,000 cubic feet a day; while at Richmond, Standard Oil Company of California is operating a 1000-barrel unit. A short while ago Tide Water Associated Oil Company installed a 35,000-gallon-a-day Multicoil process at its Avon refinery. Recent completion of a major construction program at Richfield Oil Company's Watson refinery inaugurated the operation of a catalytic unit with a daily capacity of 5,000,000 cubic feet of refinery gas.

With the higher octane value of base stocks, and the comparatively low production of excess gas from cracking operations, it is natural that the Pacific Coast refiner is carefully studying the economics of polymerization before engaging in a widespread erection of units. Some observers contend that polymerization will never really take hold on the Pacific Coast until deeper cracking is resorted to. If this view is taken as indicative of trends, the likelihood of deeper cracking will not arise until a more satisfactory basis for the curtailment for crude-oil production is agreed upon. If deeper cracking comes about, the damage already done by obsolescence will have to be remedied before all of the refiners can do any extensive cracking. Others contend that much of the Pacific Coast refining equipment could not stand the stress of higher pressures and higher temperatures without remedial work, or actual reconstruction being carried out to permit the greater demand on the cracking unit. This year will probably witness the erection of two more catalytic polymerization units on the Pacific Coast.

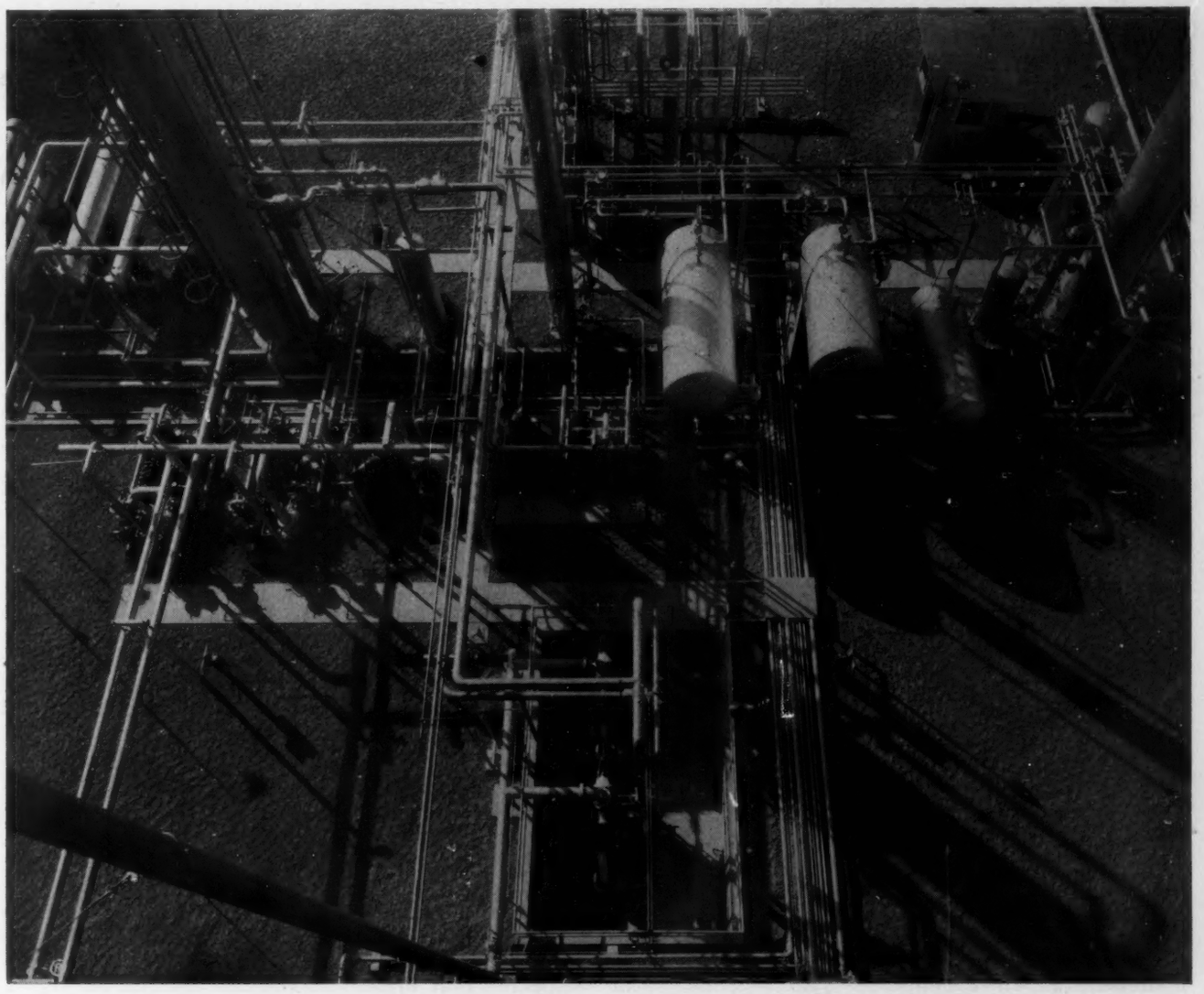
During 1939, as in the past, manufacture of lubricating oil stocks on the coast will remain in the hands of a few of the majors. These manufacturers, however, will be busily studying ways and means of improving process efficiency, and emphasis is likely to be in the direction of more solvent extracting and solvent dewaxing. Prior to the successful commercial application of solvent refining methods for lubricating oil

manufacture, it was often necessary to reject many crude oils containing excellent lubricating stock because of the limitations of the general run of refining equipment to permit the selective treatment of these special crudes. Even those refiners who were fortunate enough to be able to give selected crudes special treatment found that the old distillation method failed to give a product with good performance characteristics. With the perfection of various ways of conducting solvent refining, manufacturers are now able to separate far more completely many of the desirable constituents from crude lubricating stock. This accomplishment has served to formally entrench the solvent-extraction and solvent-dewaxing procedure as an important advancement in refining operations.

Present Pacific Coast solvent-extraction processes represent a charging capacity of 14,750 barrels a day, while the solvent-dewaxing installations have a charging capacity of 2800 barrels a day. These combined capacities of 17,550 barrels a day represent a capital investment of close to $3,500,000. This year will undoubtedly witness the expenditure of an additional $1,000,000 on solvent refining which should increase the charging capacity by another 5000 barrels daily.

That 1939 promises to be an active and a profitable year for the Pacific Coast refiner is amply justified when viewed in terms of what has been accomplished during 1938. Virtually all phases of the refining process have received attention, either through repairs to existing systems or through modernization programs involving complete renewal. Carrying out what might be termed general repair and reconstruction programs, the Standard Oil Company of California spent over $250,000 at its El Segundo refinery in changing and increasing the capacity of various facilities; while at its Martinez refinery Shell Oil Company installed a new topping unit.

The installation of cracking equipment received a full share of attention when viewed in terms of what five California refiners did. Possibly the most noteworthy installation in terms of extent is the $5,000,000 Sinclair combination distillation and cracking system installed by Richfield Oil Corporation at its Watson refinery. This plant has been on stream for some time and is living up to the expectations for it. At its Torrance refinery, General Petroleum Corporation constructed a 14,000-barrel Lummus unit; and at Bakersfield, Mohawk Oil Company constructed a 1000-barrel Dubb's combination unit. Union Oil Company of California installed a $2,000,000 cracking unit at its Oleum refinery; and at the Avon re-



Bird's eye view showing piping arrangements at Rancho Gasoline Corporation's new high pressure absorption gasoline plant at Grapevine, California. Engineered by Parkhill-Wade Inc.

finery Tide Water Associated Company built an Alco tube-and-tank system which has been in operation for some time.

The installation of reforming equipment has not been overlooked and Wilshire Oil & Refining Company has installed such equipment at its Norwalk branch for converting third-grade gasoline to what has been reported to be a good quality cracked gasoline. Viscosity-breaking has come in for its share of attention through the installation of a small unit at the Watson refinery of Tide Water Associated Oil Company. Distillate-treating also appears in the 1938 roster of expenditures by Pacific Coast refineries through the installation, by The Texas Company of California, of a cold acid treater and centrifuging system at its Los Angeles works.

Last but not least can be mentioned the steadily increasing interest in solvent refining. While no specific installations under this heading were made on the Pacific Coast during 1938, yet the progress which Pacific Coast refiners have made in adapting this system of treatment merits mention. Four major companies represent those who are using solvent-extraction systems. Shell Oil Company operates a Furfural unit at Martinez; Standard Oil Company operates Duo-Sol and SO_2-Benzol systems at Richmond; and a Phenol system at El Segundo. An SO_2-Benzol system is operated by Tide Water Associated Oil Company at Avon; and an SO_2-Benzol process by Union Oil Company at Oleum. The status in solvent dewaxing is represented by a Benzol-Ketone unit, operated by Standard Oil Company at Richmond; and a Propane plant operated by Union Oil Company at Oleum.

In addition to refining and treating, the manufacture of synthetic high-octane compounds, and the recovery of sulphur as a by-product from refinery gases, with its possible utilization in the manufacture of sulphuric acid, may prove economically attractive to other Pacific Coast refiners this year. While polymer gasoline is used to produce high-octane premium fuels, the problem of gum formation and the possible additional requirement of lead tetraethyl has served to stimulate the development of other ways of producing substances more stable chemically and capable of of bringing about a higher octane rating without adding lead. Particularly in the manufacture of aviation fuel, blends are in demand which leave no residual materials on cylinder walls, valves, or other moving parts.

In the aviation industry, high-octane means quicker takeoff, increased payload capacity, and cruising range. These demands have received added stimulation because of the trend in aviation-engine design toward greater horsepower per pound. With such a trend, it is only natural that synthetic chemistry should come into the picture. Iso-octane and iso-propyl ether are two high-octane materials now being manufactured in commercial quantity. The year should witness another installation on the Pacific Coast for the commercial production of either of these two desirable blending mediums. For the past two years Shell Oil Company has been manufacturing iso-octane at its Wilmington refinery. This company utilizes the iso-octene formed by the polymerization of the butylenes found in refinery gas. The reaction is carried out in the presence of an activated catalyst. The iso-octene is then hydrogenated to form iso-octane. While no iso-propyl ether plants have been constructed as yet on the Pacific Coast, it is probable that someone will make the attempt before long. Possibly this venture may take place next year. Iso-propyl ether is made by the chemical treatment of propene found in refinery gases. It may also be prepared by dehydrogenating the propane found in natural gas.

No speculation as to this year's activities by the Pacific Coast refining industry would be complete without mention of the probable channels through which the estimated $500,000 will be spent for research and development. With emphasis on sectional problems, research and development will continue with its fundamental studies of pyrolytic and catalytic cracking. The presentation of a paper on the Houdry process at the Chicago meeting of the American Petroleum Institute has stimulated a great deal of interest. This interest will project itself as a stimulus to the further study of catalytic cracking. Liquid-vapor phase and selective cracking will also continue to receive the attention of the research man.

A good deal of research and development work is likely to be carried out in an effort to improve the life of cracking tubes and the development of special alloys which will resist the heat and pressures imposed upon tubular goods in refinery operation. Cracking equipment itself will probably undergo changes fostered by development work. It is entirely possible that better pressure vessel linings will be made known along with better ways of combating corrosion.

The eternal search for an increase in the octane value of products will continue, and the chemist and chemical engineer will give a great deal of attention to the study of polymerization and alkylation reactions. Diesel fuels should continue to attract attention, and many a research project will be directed at the improvement of refining procedures with the hope of improving performance characteristics.

Treating methods will receive their share of attention, and efforts made to bring about added economies in acid, better control of the treating procedure, the subsequent control of gum formation, as well as the improvement of gum inhibitors. Last but not least, asphalt and asphaltic materials will receive attention. Attempts will undoubtedly be made to bring about better and more stable asphalt emulsions along with the admixture of other substances which will contribute to the overall physical properties and durability of the various asphalts applied to a host of industrial uses.

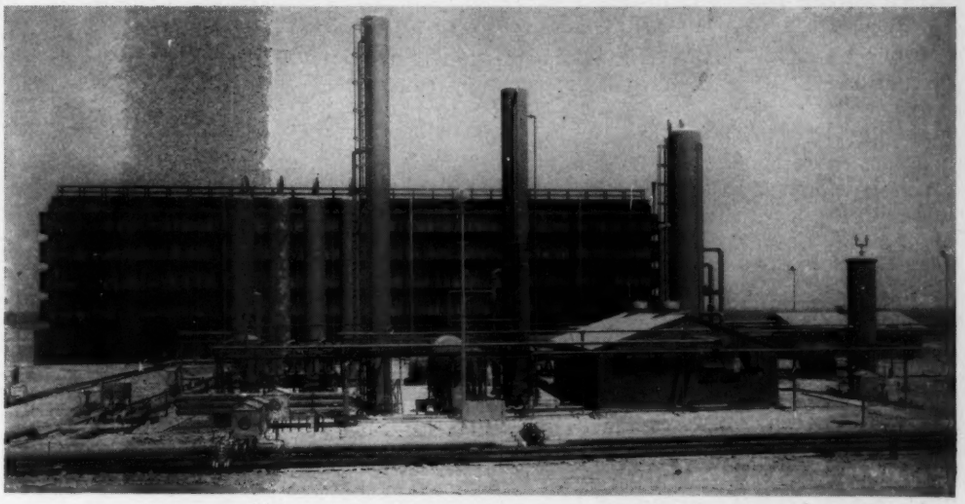
NATURAL GASOLINE OUTLOOK

Nineteen hundred thirty-nine will be another busy year for Pacific Coast natural gasoline manufacturers. If expected compensating factors operate in field developments and drilling programs, the amount of wet gas produced will yield close to 650,000,000 gallons of natural gasoline. With a comparatively few companies engaged in gasoline manufacture, it is to be expected that market conditions will remain stable, with channels for utilization active. California will contribute at least 30 percent of the 2,100,000,000-gallon United States natural gasoline production.

The gasoline manufacturers' hopes are tied so closely with those of the producer that no estimate of the year's activities in California can be made without using field developments as a background. Doing this, the conclusion is that the trend will be a mixed one. The newer field developments in the San Joaquin Valley have brought about the erection of several high-pressure absorption plants which are

still operating far under capacity. Whether or not these new fields continue to expand will determine whether or not the 1938 level of natural gasoline production will be maintained, or exceeded. In the older fields, well repair and redeepening programs are being carried out by various concerns which some take as a restimulation of hope that declining gas volumes may be controlled.

Thirty-five miles northeast of Bakersfield Continental Oil Company recently established the Wasco field. In this area Standard Oil Company of California brought in a deep producer with a substantial quantity of gas. If 1939 should bring additional completions to this district the justification for the erection of a high-pressure gasoline plant may be realized.



General view of Belridge Oil Company's high pressure absorption plant at North Belridge, California.

The center of activity for the Pacific Coast natural gasoline industry is in the San Joaquin Valley, with Los Angeles basin next. Important deep well developments in such fields as Ten Section, Greeley, Rio Bravo, and North Belridge Extension have served to stimulate natural gasoline manufacture in the San Joaquin Valley. In the Los Angeles basin area the discovery of the Wilmington and El Segundo fields brought about the construction of new gasoline plants. In this area the discovery of the deep sand in the Torrance-Redondo sector, the extension of the Athens-Rosecrans field, and the recent westward extension of the old Montebello field have brought many remodernization and construction projects to the gasoline manufacturer.

In the Rio Bravo field, 25 miles northwest of Bakersfield, many deep producing wells of substantial proportions have been completed. The volume of wet gas reached proportions justifying the erection of a high-pressure gasoline plant. Such an installation began operations last year after having been constructed jointly by Union Oil Company and Superior Oil Company at a cost of $500,000. The plant was designed with a 20,000,000 cubic foot per day capacity. At present, it is operating on 5,000,000 cubic feet of gas and producing approximately 3000 gallons of gasoline daily.

In the Greeley field, 5 miles southeast of Rio Bravo, the Standard Oil Company of California has been actively developing its properties, and the extent of this development has justified the erection of a high-pressure natural gasoline plant, with a daily capacity of 30,000 gallons. This plant is reported to be manufacturing less than 10,000 gallons per day. However, the equipment was laid out with ample capacity for future expansion.

Seven miles south of the Greeley field lies the Ten Section area. This section has been developing steadily, and the 15,000,000 cubic foot a day high-pressure gasoline plant, built by Shell Oil Company two years ago, still has ample capacity for any future field development.

In the Los Angeles basin, the Wilmington field, 22 miles southwest of Los Angeles, has contributed substantially to natural gasoline production. In this area General Petroleum Corporation is operating a plant with a production capacity of 85,000 gallons a day. It has been estimated that this plant is operating at about a fourth of its capacity. Lomita Gasoline Company gathers gas from this field, particularly from those wells east of Ford Avenue, and transports the gas through a compression plant and a 16-inch line to the Lomita Plant at Signal Hill proper, a distance of 6 miles.

The development of El Segundo, 15 miles west of Los Angeles, having come to a standstill, the two natural gasoline plants are caring, with ample excess capacity, for all the wet gas produced. Gasoline production in this section averages about 12,000 gallons a day, of which approximately 8000 gallons are manufactured by Richfield Oil Corporation, the remainder by Ohio Oil Company. Both concerns operate low-pressure plants.

Approximately 15 miles east from Los Angeles lies the Montebello field, the westward extension of which has stimulated wet gas production. The only gasoline plant operating in this district is that of The Texas Company, the Universal Consolidated Company plant, and the St. Helens Petroleum Company plant having been shut down about a year ago. The extent of the western expansion of this district has not yet been determined, and the hope has been expressed that the too rapid town lot development of oil properties will be avoided.

The discovery of a deeper sand in the old Torrance-Redondo field 18 miles southwest of Los Angeles, has increased wet gas volumes. Most of the gas produced in this district is handled by the gasoline plant operated by Coline Gasoline Corporation. The extension of the old Athens-Rosecrans field, through the discovery of a deeper zone, has increased the wet gas output to the extent of adding to the load treated by Union Oil Company's low-pressure installation. Also handling some of the gas in the western

section of the new development is a gasoline plant recently constructed by Universal Consolidated Oil Company. This plant has a daily production capacity of 6000 gallons. Within the past 90 days Cowan Oil & Refining Company has rebuilt its old plant in the northeast section of the field. Under present operating conditions, the capacity of the remodernized unit is estimated at 5000 gallons a day.

In viewing the possible trend which plant design on the Pacific Coast might take next year, should another plant or two become necessary, the immediate impression gained is that of many divergent opinions as to just what would constitute the best plant layout. The only definite conclusion that could be reached is that any new plants in the deep field areas of the San Joaquin Valley will more than likely be high-pressure units; with any new units in the older fields outside of the San Joaquin Valley probably being low-pressure.

If any low-pressure absorption plants are built next year, the design will not vary greatly from that which has proven effective for so many years on West Coast gases. For example, low-pressure plants operating at 40 pounds will probably contain 17-plate absorbers discharging rich oil into a vent tank where the vapors are picked up and sent to a recompressor. The rich oil will find its way through conventional banks of heat exchangers, and then into a flash tank. From the flash tank the heavy vapor will go into a fractionating still containing about 10 plates in the lower stripping section and about 10 plates in the fractionating section. The condensate will be dewatered as usual and sent to the rectifier.

In finished gasoline rectifiers the trend is likely to be toward higher operating pressures and the use of a greater number of plates. It has been pointed out that the greater the number of plates the lower is the reflux ratio required, with resulting temperature economies. Several 50-plate columns are now in operation. Any tendencies to increase column size are likely to be limited by structural factors, such as the strength of the materials for the pressure to be carried, etc. Six feet is likely to be thought of as the maximum in diameter, with no limit placed on height. Some designers are likely to hold that too large a column brings a big drop in plate efficiency when the volume of throughput drops. The higher the gas velocity, the better the plate efficiency. Among the many miscellaneous accessories to good rectifier operation it will continue to be evident that the bubble cap tray, is steadily displacing the perforated tray in new and rebuilt towers. The main objection to the perforated tray appears to lie in its lack of a positive liquid head. The amount of liquid on it varies with vapor velocity and it is not uncommon for perforated trays to dump when a gasoline is rectified which is low in percentage of iso-butane and lighter constituents. Centrifugal pumps will undoubtedly remain popular because of smoothness of pumping, but where flexibility is demanded the reciprocating pump will still be necessary. Outside reboilers, or heaters, should continue to attract more attention than internal heaters for rectifiers. Reflux pumping will, on the whole, be preferred to top condensation.

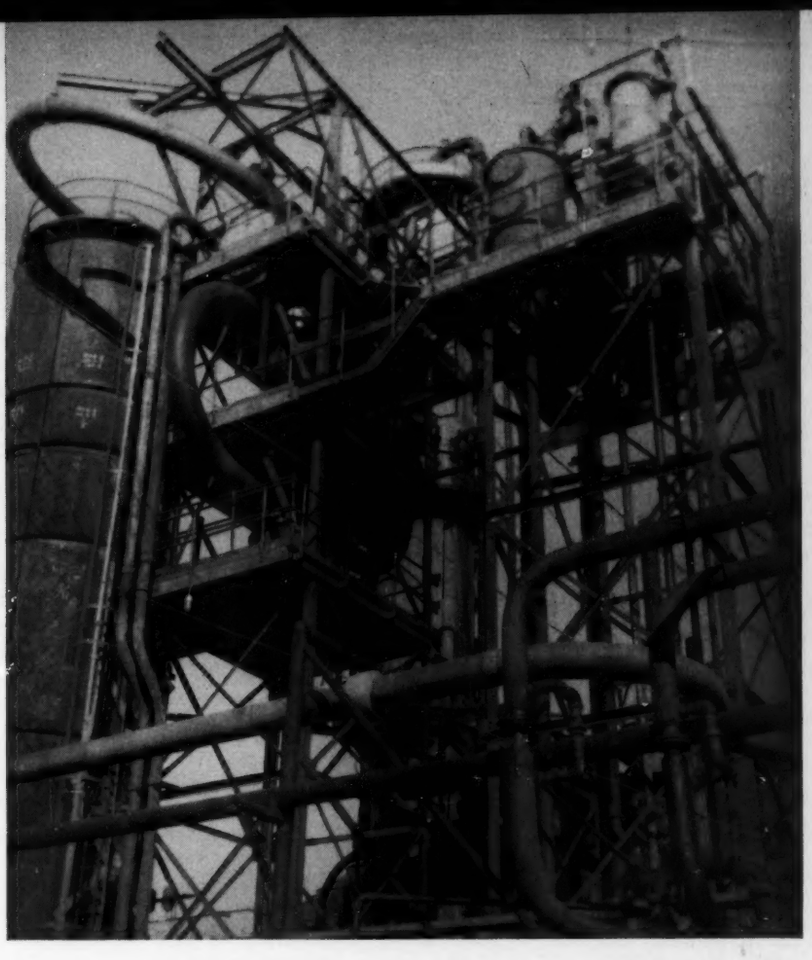
Any high-pressure plants constructed in the San Joaquin Valley will probably be designed to operate at 450 pounds, or the same pressure as those units now in operation. Not only the advantage of being able to handle large volumes of wet gas more economically but the saving of the compression cost for gas turned over to utilities, will probably be an added reason why San Joaquin Valley natural gasoline manufacturers will continue to erect high-pressure units. By compressing the wet gas to 450 pounds the volume of absorption oil required can be greatly reduced, as well as the size of plant equipment. Moreover, with the cost of dry gas compression between three quarters and a cent-and-a-half a thousand cubic feet, it is attractive to the gasoline manufacturer to employ the high-pressure operation to decrease the size of his plant and get the maximum price for the dry gas. High-pressure dry gas is also finding increasing value in certain areas in California for repressuring operations.

Within the past two years the necessity of designing better engine mufflers has engaged the attention of power engineers, and notable progress in this direction should be forthcoming during the coming year. Noise abatement and heat dissipation are the major difficulties demanding correction. Noise abatement is essential for plants near residential districts, while ways and means of improving the control of heat dissipation is necessary because of the annual toll of damage to muffler foundations and adjacent flooring, as well as the promotion of the rapid oxidation of the muffler body itself.

The Pacific Coast liquefied petroleum gas industry, small though it may be, has enjoyed a profitable year, which augers a continuance into 1939. It is expected that the production of liquefied petroleum gas this year will reach a volume close to 40,000,000 gallons, or approximately 10,000,000 gallons greater than the 35,000,000 gallons predicted for 1938. California liquefied petroleum gas sales next year are likely to be about 20 percent of the national figure.

In terms of the liquefied petroleum gas fractions propane and butane, the major portion of the commercial distribution is in terms of a propane-butane mixture. The bulk of the propane-butane mixture is used as fuel for internal combustion engines, a smaller proportion being used for gas manufacturing. Pure propane still finds a major outlet in domestic appliances, particularly individual tank units for dwellings. Of the commercially pure butane sold on the Pacific Coast, approximately one-fifth of it finds application in certain types of domestic installations, two-fifths in gas manufacturing, with the remainder being used for certain types of fuel requirements in internal combustion engine equipment. In transporting these liquefied petroleum gases, most of the propane is moved either in cylinders or drums, while most of the propane-butane mixture is moved by tank trucks or cars.

The Pacific Coast liquefied gas industry has developed slowly, and its present position results from sound planning and efficient sales programs designed to educate the consumer. Chief stumbling block to the rapid expansion of the liquefied petroleum gas market has been that the use of the commodity involves some measure of capital investment and a considerable amount of education regarding its use. Good sales campaigns, and the perfection of equipment for utilizing the mixtures are steadily contributing to the growing market requirements. However, most concerns engaged in this business cannot as yet report substantial profits. Most sources agree that what is to be gained from the marketing of liquefied petroleum gas will result only from a long pull, hence most of the money invested has been placed with this long-range realization in mind.



Refinery Modernization

R. C. OSTERSTROM
Executive Assistant and Chairman Refinery Control Board, The Pure Oil Company

IT has been said that nothing fundamentally new has been developed by the petroleum industry along the lines of oil refining. This statement is somewhat true when we remember that today's modern tube still embodies combustion and heat transfer principles of the type used in connection with the well known water tube boiler. Likewise, the modern fractionating tower, common equipment in the manufacture of alcohol long years ago, has rather recently been adapted to the oil industry. The list could go on indefinitely.

However, it has also been definitely proven that the application of science to the refining art is now so rapid that today's strictly modern plant may become largely obsolete in a period of less than five years.

It becomes obvious immediately that technical knowledge of a high order, as well as experience, is required to adapt scientifically to petroleum refining the ideas and practices developed by other industries. It is not meant to leave the inference that the petroleum refiner is devoid of originality.

Usually, modernization or replacements become advisable for any of three general reasons: One—where important new developments have occurred in methods of manufacture, making completely obsolete, or nearly so, existing manufacturing equipment; Two—where a market for new products has existed for some little time, and such market has expanded to the point where it would be definitely profitable to enter into the manufacture of such new products. Most often, existing

A WELL organized plan of work and a highly coordinated method of procedure which brings into the scheme of refinery modernization all of the men in all departments responsible for design and operation is a commendable achievement. In the accompanying discussion, R. C. Osterstrom, executive assistant and chairman of the refinery control board for The Pure Oil Company, gives in detail the story of the planning and the work of bringing a refinery to modern efficiency. He tells of the work done by the chemists, the chemical engineers, the process engineers and refinery management. In addition the picture is completed through the work of construction engineers, maintenance, mechanical, metallurgical engineers as well as the combustion engineers, draftsmen and the designing and field engineers, all of whom bring into being the completed plan of modernization before the executive division of the company is concerned with approving the final recommendation.

The article is reprinted from *Pure Oil News*.

equipment does not permit their manufacture, in which event partial or complete replacement with equipment providing greater flexibility is undertaken. The third reason involves the case of a new development in some industry for a petroleum product to fit a new demand. Petroleum refining exists only because of public demand for its products. These demands are continually changing because of advancements being made in machinery design, automotive design, etc. For example, a change in a type of driving gear on an automobile brings about a new problem in lubrication. The sales automotive engineers make the problem known to the petroleum chemists, and the chemists work out a new product to serve the purpose. Then, the chemical engineers are called in to advise on the most economical method of manufacture in the petroleum oil refinery. It will be seen that the research and development laboratory is essential to every oil company operating an oil refinery.

It is becoming more and more apparent that the very nature of petroleum is fast putting it in the classification of a chemical industry, and this, coupled with the engineering problems involved, points out the importance to the refinery of the chemical engineer, as well as the chemist. The petroleum refinery chemical engineer, therefore, besides being alert to developments in the oil refining and other industries, must also be practical from the business man's viewpoint, and be cost-conscious. With this background, the need for modernization as it develops from an economic standpoint is the chemical engineer's knowledge. Likewise, these engineers are informed as to the most practical method of modernizing with the newest equipment available, or likely to be available, in the light of the best chemical engineering principles, coupled with the results of the company's own research program.

In collaboration with the sales people and refinery process engineers, even though no research work is required, the chemists work out specifications to be met of products demanded, which must be given prime consideration by both the chemical engineers and process engineers in a modernization program. These same specifications are given the refinery management to be followed in operating the plant. In addition, a system is in effect wherein the products at the refinery are tested by resident chemists to see that they actually meet such tests before being shipped.

The chemical treatment of products, such for example as the treatment of gasoline for removal of corrosive compounds, is generally a research problem worked out jointly by the chemists and chemical engineers.

The need having been established, and having, as a result of such study, narrowed the choice of equipment to a very few in number, the recommendations are then brought before the group of process engineers. Since the management of the refinery where the new apparatus is to be installed will be expected to operate that which is finally selected, they are called in from the field for consultation at this stage. Together with the process engineers, the day to day accumulated plant experience of this group is added to the chemical engineers' knowledge in order to secure final selection of the proper apparatus from the standpoint of ease of operation and the maximum in operating efficiency and economy.

The process engineers are concerned with the ability of the equipment selected to meet the flexibility of operation required in order to manufacture products of the required specifications from dissimilar crude oils. These engineers must have technical ability to check the capacities of towers, heat exchangers and condensers, and calculate the efficiency of fractionating equipment. The chemistry and technology of cracking must be understood in order to determine the temperature and pressure conditions best suited for the operations planned. In the design, the process engineer also must be familiar with the largest refining developments in order to be in a position to meet the standards of quality demanded by the public at the lowest cost to the consuming public.

In selecting the size of tubes in distilling and cracking furnaces, the surface volume ratio must be calculated to insure the proper velocities and necessary time element to prevent premature coking and excessive decomposition of the oil being processed. Several furnaces may be used in processing one grade of crude in order to establish the best conditions for maximum yields and anti-knock values by cracking several components parts separately. The process engineer must select furnaces that will, within reasonable limits, meet changes in crudes and improvement in products that may be demanded over the succeeding years.

Fractionation deals with the separation of the many oil hydro-carbons into groups according to their boiling points. In designing a fractionating tower the number of pans or bubble trays required must be carefully calculated. Vapor velocities, liquid down-comer areas, and bubble cap design must be held within limits established by experience. Accessibility for cleaning and repairs must be watched. Provisions must be made for draining bubble cap trays and for taking samples as well as pressure and temperature readings. Connections must be provided for control equipment, and connections must be installed to permit injection of corrosion resisting media such as ammonia.

Gasolines produced from distillation of fresh crudes and cracking must undergo further fractionation for the removal of very light gases dissolved in the gasolines. If not removed, these bases promote vaporization in the automobile gasoline feed systems during hot weather and create a condition known as vapor lock. The present conventional method for the recovery of natural gasoline from the wet natural gas as it occurs at the well is by the absorption process. This process involves contact of the wet gas with absorption oil and subsequent separation of the absorbed gasoline from the oil. The recovered raw gasoline is then stabilized to the desired vapor pressure. This process involves the pumping, heating and cooling of relatively large quantities of absorption oil with high requirements of steam and water. This fractionating step is known as stabilization and is accomplished in a tower operating at a pressure high enough to permit condensation for subsequent removal of the very light hydro-carbons which would exist as gas at atmospheric temperatures and pressures.

Heat exchangers play an important part in modern refining in that they provide a means of utilizing waste heat that would otherwise be given up to the cooling water. They are also used for final cooling and condensing where efficient compact equipment is desirable in the interest of water economy. In selecting exchanger equipment, the maximum and minimum flows must first be established together with the temperature change that is desired. Once these conditions are determined, the heating surface required is calculated, taking into account fouling factors that affect the heat transfer over long periods of continuous operation. If the temperature range is large it may be desirable to use several exchangers in order to obtain a moderate rise through each exchanger and reduce expansion strains. It is desirable also to keep the size and weight down in order to facilitate handling for cleaning and repairing. At the time of erection, provisions are made to secure operat-

ing data such as pressure drops, quantities and temperatures for checking future actual operations.

Likewise included in the scope of the process engineer's work is instrumentation—the science of measurement and control of the various factors vital to processing oil in the refinery. These factors may be classified as temperature, pressure, rate of flow and liquid levels. On all new refinery construction or modernization, the flow sheet, showing desired quantities, temperatures and pressures, is carefully analyzed for adoption of the proper instrument and control equipment. First cost and ultimate operating cost and efficiency have to be considered, as well as the minimum maintenance expense. The practical answers to these and many other questions come from the accumulated years of experience of plant managements, process engineers with operating problems and their instrumentation, plus the constantly improved products of a number of instrument manufacturers. Many of the processes used today would not have been possible if the proper instruments had not been developed.

The process engineers are in close touch with the sales people and crude oil supply people. From their contacts with sales they have a long range view of the product demand on the part of the public, and from the crude oil supply people they have a long range view as to probable crude receipts. These must be fitted in to the chemical engineer's recommendations for modernization.

Generally speaking, petroleum oil refining companies are using to an increasing extent the several large engineering firms that have specialized in this field. Working against keen competition, and faced with an increasing demand for new equipment, they have been obliged to do considerable independent research work and make every possible improvement in construction methods. Price competition forces such firms to search out reliable organizations who have developed better and cheaper methods of fabrication. An example of what is meant by the development of better methods of fabrication would be to look back about fifteen years ago, when we find the engineering staff of a fabricating company of necessity having to detail its shop work in its entirety. On a unit involving steel plates, each separate plate entering into the construction was laid out individually and every rivet hole had to be accurately located on paper by the draughtsman. Where pressure was involved, it necessitated the use of reinforcing plates both inside and outside of the joints so that the required strength was given the joint. Obviously, being put together with rivets, it meant that the main steel plate and the two reinforcing plates had each to be punched for each rivet driven, which called for the maximum in accuracy in laying out the rivet holes. To make the rivet leak-proof, caulking had to be resorted to. This was done by the use of an air driven, bunt nosed tool worked around the outer edge of the rivet head where it touched the steel plates. The thickness of the plates and the joints depended on the pressure desired to maintain, so that an eight inch joint was not unusual. When this situation existed, field drilling of the holes followed by reaming of each hole had to be resorted to.

The inability to design a riveted joint equally as strong as the plates it joined, to meet the new demands of the petroleum refiner, was one of the strong incentives for those in the welding field to develop the welding art to its present stage of perfection. Today, construction companies responsible for the design of refinery equipment have no hesitation in trusting the strength of welded joints, so that a vessel built for pressure is nearly always welded and not riveted. With the new and latest developments in welding it is possible for the designing engineer to minimize the losses in excess weight and increase his pressures to such points where the vessels can be economically manufactured. Parts made of fabricated steel plates have replaced castings and forgings in many instances. Hydraulic presses have taken the place of the hard and accurately hitting hand of the blacksmith. The welding machine has replaced the punch, the reamer, the riveting machine, the rivet furnace and the caulking tools, and has increased the scope of the work that can be undertaken.

Out of welding came another tool—the X-ray for photographing heavy steel plates. This equipment has been developed to the point where plates in excess of four inches in thickness are readily photographed. This development makes clear to the skilled interpreter the exact condition of an electric weld from surface to surface. Through its aid the nature of the imperfection in the weld can be analyzed and the technique of welding has been developed to the point where it is unusual to have an imperfection. The integrity of the weld is no longer a matter of question; it is a matter of record. With the introduction of the X-ray, a routine check is possible as a constant measure of the effectiveness of the weld.

The company's refinery construction engineers are now presented with a complete description of the project; that is to say, complete details of the oils to be processed, the method of processing including temperature and processing conditions, products to be produced with complete specifications of such products, complete specifications of all materials making up the processing equipment, number and kinds of temperature and pressure controlling and recording instruments, and in fact, complete in all the detail necessary to enable them to secure proposals for construction from the various large construction engineering firms. When these proposals are received by our company, they are first checked by the process engineers. Such changes in the flow diagram are made as are deemed advisable, and then the contemplated project is next passed on to the maintenance engineers. These men are mechanical and metallurgical engineers and also expert in their specialties.

The project is reviewed by the mechanical engineers first by considering performance of existing units with a view of eliminating operating difficulties and maintenance expense experienced as caused either by unsuitable materials or unsuitable design. The general contract and specifications of a project must be carefully checked to see that each individual piece of equipment entering into the project meets the company's standards as to design stresses which will govern the thickness and size of the various pressure vessels, the metals which are involved in the construction, all with a view of insuring safe operation with a minimum of future maintenance expense. The specifications on a major project must be reviewed in complete detail on all such items as pressure vessels, still tubes and furnace fittings, and other accessories. Not only are the design stresses and metallurgical aspects carefully reviewed, but mechanical performance must be kept in mind at all times. Past experience is the most important criterion of projected new equipment. There have been many cases where theoretically good ideas and combinations of materials have not worked out well in practice. The maintenance engineers are in touch at all times with other oil refining

company projects; their failures are noted and avoided in our company's contemplated construction, and where new developments have been made by others, such ideas are incorporated.

In addition to the purely mechanical aspects of the project, it is necessary for the maintenance engineers to keep in close contact with the process and chemical engineers so that they may be familiar with the kinds of crudes to be run, so that corrosion problems are adequately taken care of. One of the largest items of expense in a cracking plant is the continual replacement of parts which are consumed by corrosion. Here the matter of economics comes very prominently into the picture. It is possible, by the use of relatively rare and therefore very expensive alloys, to reduce the corrosion expense to a very negligible quantity, but if such materials are used the investment cost becomes so high as to overbalance the decreased maintenance expense. It is, therefore, necessary to strike an intermediate point so that the original cost of the materials will not be prohibitive, nor on the other hand, the replacement expense with the consequent outage time of the unit will not be too high. In solving this problem, the maintenance engineers will have drawn not only on their past experience but on their contacts with the metals industry, so that the greatest advantages may be taken of all improvements which have been made by the metallurgists in the metals industry. Perhaps in no industry has metallurgy played so important a part as it has in petroleum refining. Here, metal equipment must operate at temperatures ranging from —70° F. to 2000° F.

Another very important aspect of a new project is the consideration of existing facilities of a refinery with respect to utilities such as air, water, gas and steam. It is necessary to determine the most economical method of driving the pumps used in pumping oil and water required for the project.

While thousands of dollars have been spent for new equipment to bring modern shops up to the efficiency necessary to meet demands, necessitating consigning to the junk yard antiquated machinery, the company's mechanical engineers must constantly keep in touch with such shops and be able to approve or disapprove the letting of sub-contracts on the basis of ability of such shops to turn out the type of work required in the specified time. Another factor which must be examined closely when selecting mechanical equipment for a new project are the shop facilities existent for making any necessary repairs. The increasing size of units renders a great deal of our present equipment unsuitable for the satisfactory maintenance of some of the newer mechanical equipment. It sometimes develops that it is more economical to forego the installation of the new shop machinery and carry sufficient new parts on hand for repairs so as to allow sending the old parts back to the factory for repairs when they become worn.

The project having been considered by the maintenance engineers, the next problem to be considered if steam is to be generated, is the latest and most economical way of producing it. This is given to the combustion engineers. Generally speaking, the engineer supervising combustion is either a mechanical or chemical engineer specializing in combustion. This includes not only steam generation, but also fuel economy. The function of the combustion engineer in the design of oil refining equipment is to not only make certain that fuel burning equipment is capable of properly burning the selected fuel with a minimum loss due to oil refining equipment is to not only make certain that the arrangement and amount of heat absorbing surfaces are such as to absorb the heat released in the furnace at a rate which will prevent excessive temperatures from existing in the walls of the tubes which carry the oil through the still.

While these principles have been recognized and followed in the design of steam boilers for years, it does not follow that a good steam boiler design would be a good design for an oil still. This is due chiefly to the difference in the thermal characteristics of oil as compared to water. There are two principles which are common to both steam boilers and oil stills which must be followed for the economical operation of each, and these are: First, the burning of any fuel with the least amount of excess air results in the maximum possible flame temperature; and second, the most rapid method of heat transfer for flame to heat absorbing medium is by means of radiation. When these points are considered, together with the difference in the thermal properties of oil and water, and also the item of holding tube wall temperatures to a permissible maximum amount, it is obvious that a greater amount of heat absorbing surface must be exposed to the flame in an oil still, as compared with the amount to be exposed in a steam boiler operating at the same fuel efficiency.

In addition to these items, the use of greater amounts of radiant heat absorbing surface and its arrangement forces more consideration to be given to the selection of fuel burning equipment and its arrangement. This is highly essential in order to make it possible for each tube and portion thereof to absorb the same amount of heat as any other tube in the same section of the furnace.

The arrangement of the tube surfaces, together with the length and height of the furnace, forces consideration of the material and method of supporting the refractory material used in the furnace walls. Many such walls were formerly built of 9 inch firebrick laid in such a manner as to be self-supporting. This arrangement forced the use of thick walls and various methods of allowing for expansion. These walls added considerably to the total weight of the furnace structure and the weight to be carried by the foundation.

In more recent years two developments permitted an improvement in furnace wall construction and these were the adoption of the supported type of construction which provided for the use of special shaped refractories held in place by special castings and supporting steel work, and also the development in insulating refractory for use in a similar manner.

The item of fuel burning equipment for oil stills of tubular design, consists primarily of a selection of either gas or oil burners or a combination of the two, and their installation in such a manner as will provide for uniform heat distribution, together with ease of control by the firemen.

The combustion engineer of the oil refinery is also concerned with the problem of stoker selection or pulverized fuel equipment for the operation of steam boilers, together with the auxiliary items of coal handling and storage equipment, also ash handling and disposal.

Due to the frequently changing prices of the various available fuels, together with the fact that most modern refineries generate enough refinery gas for the operation of oil stills, it is necessary that the steam generating plants of the modern refineries be so equipped that they can readily change from coal to oil or gas at a minimum expense, and with as little change in operating labor as possible. It is therefore essential that up-to-date

[*Continued on page 36*]

Effects of Gas Injection on Natural Gasoline Plant Operation

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FOR the purposes of this paper I am using the term "gas injection" to cover any operation involving the forcing of gas into a producing formation for the purpose of facilitating, or increasing the ultimate total of, recovery of oil from the formation. Considering the conditions in the producing formation, the source of the injected gas is immaterial. In other words, regardless of whether the operation falls in the class of "pressure maintenance" or "repressuring", the act of injecting gas into the formation produces the same results as far as the formation conditions themselves are concerned. Depending upon the relations between the producing factors, which have been discussed, the injection may retard the rate of pressure decline in the formation, or may stop such decline altogether, or may actually raise the formation pressure.

Although the benefits of gas injection are felt most directly in the production of crude oil, the conservation of natural gas which it affords will obviously have far-reaching effects on natural gasoline operations. These effects are of four different types, and are as follows:

1. Effect on quality of the wet gas.
2. Effect on quantity of the wet gas.
3. Effect on the life of the plant operation.
4. Effect on plant design.

These effects will be discussed in the order named:

EFFECT ON THE QUALITY OF THE WET GAS

It is obvious that if dry gas is returned, or injected from another source, into a producing formation for a long enough time, the gasoline content of the wet gas taken from the formation will gradually decrease. If such an operation were continued until the formation had been completely stripped of its volatile liquid contents, the returned gas would of course finally circulate through the dry formation without any change in its composition. Thus the first effect we may expect is a gradual reduction in the gasoline content of the wet gas, and this general theory is supported by experience.

A mid-continent operator reports the following data from a field in North Central Texas. The oil pool covers about 1500 acres, and produces 41° A.P.I. oil from a sand 15 feet thick at a depth of from 1150 to 1200 feet. The structure is made up of lenses and interbedded shales, with consequent irregular porosity and permeability; thus the nature of the formation favors channeling between input wells and producers. The effect of such channeling was minimized as far as possible by careful selection and mechanical treatment of the wells. The field has no water-drive; the gas injection was used for the purpose of increasing oil recovery.

Figure 1 shows the operating results for the years of from 1926, just before gas injection was started, to 1931. At the beginning, only the dry gas from the gasoline plant was injected; shortly thereafter gas from an outside source was added.

The most significant points illustrated on this chart, from the standpoint of the natural gasoline plant operator, are the increase in the quantity of gasoline produced, and the lengthening of the plant operating life. In 1926 the production was at a low ebb; operation would have been discontinued in a few months. After gas injection was started the production of gasoline increased sharply, and did not reach the low level of 1926 until about 4 years later. This operation shows, on a small scale, the principal effects of gas injection in a depleted field on gasoline plant operation.

Two other gas-injection operations, now 12 years and 6 years old, respectively, have each shown a gradual decrease in the gasoline content to practically 80 percent of the initial value. Based upon the assumption that the rate of oil production has been kept constant, these same properties have shown an increase in gas/oil ratio of about 30 percent, so that the gasoline production from the gas is now about 104 percent of the original production. The operators report that both of these gasoline plants were about to be shut down when the gas injection was started; however, due to the improvement in production caused by the injection program they are still in profitable operation.

Still another operator reports a field about 15 years old, in which the gasoline plant was shut down about 2 years ago, on account of exhaustion of the gas. Injection of gas from an outside source was started last year, with the result that the produced gas volume has now built up sufficiently to permit profitable operation of the plant. In addition, the rate of oil production has been exactly doubled by the gas injection.

In two of the most recent applications of gas injection, respectively, about 10 months and 18 months old, no appreciable change has been observed yet in the quality of the gas produced; if anything, the gasoline content has tended to increase. This is undoubtedly due to more careful selection and management of wells, since all production has been shifted

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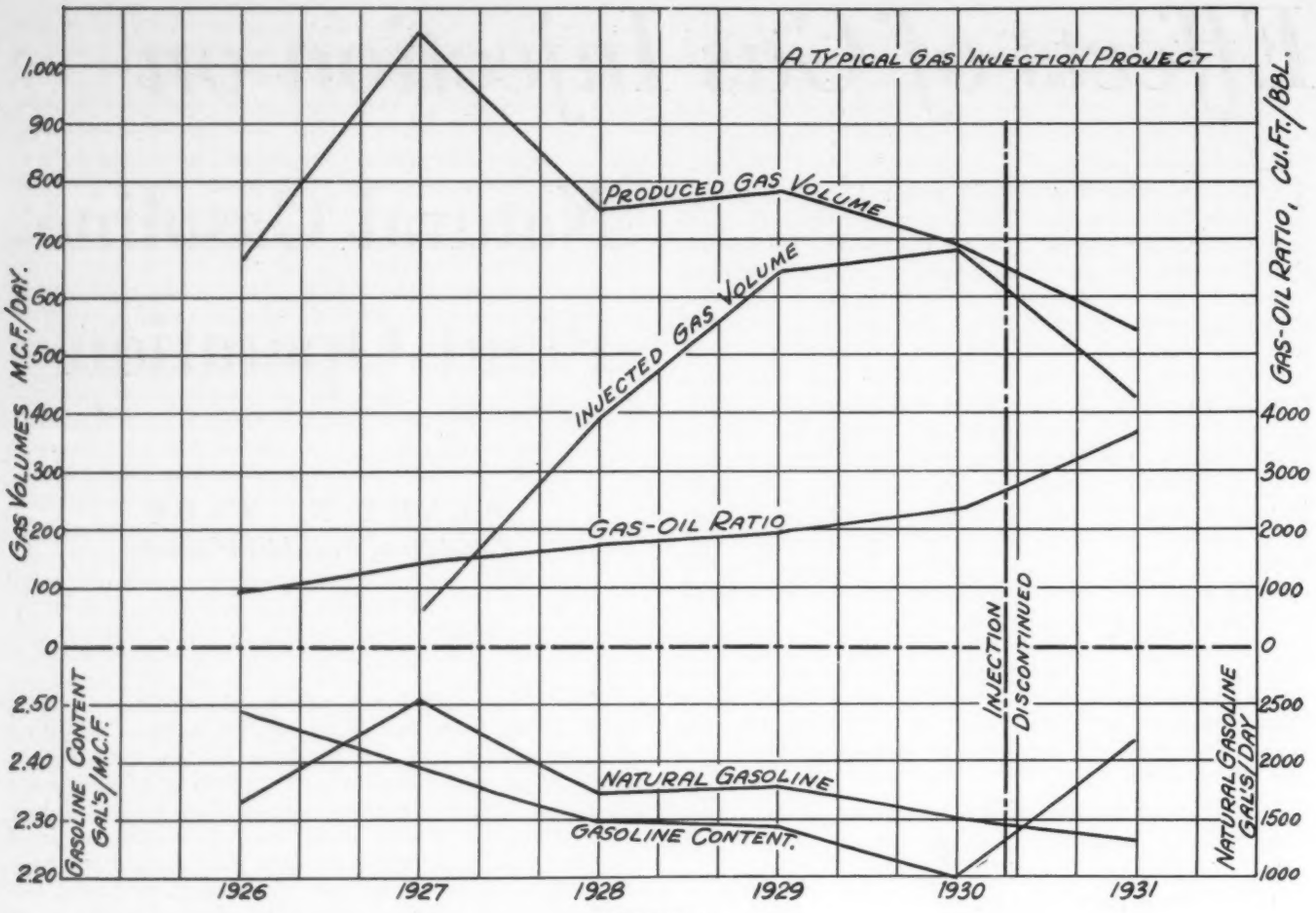

FIGURE 1

to wells showing the lowest gas/oil ratio in order to conserve compressor horsepower.

In the older of these two applications, the gasoline content of the gas, which is trapped out of the oil at about 500 lbs./sq. in. pressure, has actually increased from 0.365 G.P./M. to 0.436 G.P./M., while the gas/oil ratio has decreased from 6,230 cu. ft/bbl. to 5,060 cu. ft./bbl. These two tendencies about offset each other, so that the gas now yields 2205 gallons of gasoline per barrel of oil produced as compared with 2.272 gals./bbl. before gas injection was started. Thus, the gasoline plant is producing practically the same amount of gasoline from about 19 percent less gas, the quantity of crude oil produced remaining constant in this case. In time, of course, the normal trend toward lower gasoline content and higher gas/oil ratios will set in.

EFFECT ON QUANTITY OF WET GAS PRODUCED

It is evident that, as liquid materials are withdrawn from the formation, the injected gas will have increasing opportunity to channel or by-pass from the input wells to the producing wells through the drying formation, and that therefore, the gas/oil ratio in the producers will eventually tend to increase. This tendency can be offset for a time by progressively taking production from wells lower on the structure, but this can be done only out to the limits imposed by edge-water.

This tendency is clearly shown in the data presented in Figure 1, where the gas/oil ratio is seen to increase about 38 percent over the period covered.

From the standpoint of the natural gasoline plant operator, this tendency will at least partly offset the decline in gasoline content of the gas, so that his plant production will tend to remain nearly constant throughout the life of the field, assuming the rate of oil production is nearly constant.

EFFECT ON LIFE OF GASOLINE PLANT OPERATION

In all of the above discussion it is apparent that gas injection offers a means of bringing dead properties back to life, and of greatly prolonging profitable operation in a new field if pressure maintenance is started early.

Assuming that the cost of the injection operation is justified by savings and increased recoveries in the production of oil, so that no part of it is chargeable to the gasoline plant, the plant operators automatically saved the expense of installing compressors for gathering gas until the structure is nearly completely exhausted of both gas and oil.

Finally, if the gasoline plant operator shares in the revenue from the sale of dry gas, it is obvious that the gas saved by return to the formation affords a reserve of future income which may permit profitable operation for many years beyond the time when the plant would have to be shut down if the gas were wasted.

SELECTION OF TRAPPING AND GASOLINE PLANT PRESSURES

The selection of operating pressure conditions will, of course, depend on the local circumstances

surrounding each operation. In general, the cheapest installation will result if a maximum of gas is separated from the oil at the highest possible pressure, since the suction pressure at the compressors determines the horsepower required to pump a given volume against a fixed discharge pressure. For example, assume that the wells produce with a gas/oil ratio of 5,000 cubic feet per barrel, and show a well-head pressure of 2000 pounds per square inch. The primary trap pressure might be 1500 pounds per square inch, in which case something like 4,000 cubic feet of gas per barrel would be taken out of the mixture at this pressure, leaving only about 1,000 cubic feet per barrel of gas to be removed by separators at lower pressure. The compressor horsepower required to pump this 80 percent of the total gas from 1500 pounds suction to the injection pressure of say 3000 pounds, would be only about 40 percent of that required to raise it to the same pressure if the primary separation were made at 600 pounds.

In this connection I should mention that the phenomenon of "retrograde condensation" may prohibit the use of primary trap pressures much over 1000 pounds, unless for economic reasons there is no objection to stripping the oil of some of its lighter liquefiable fractions and returning these materials to the formation. As a matter of fact, such return may actually be desirable for the purpose of reducing the viscosity of the oil in the formation, and thus facilitating its flow to the producing wells. "Retrograde condensation" simply means that above certain limits of pressure the familiar tendency of vapors to liquefy with increasing pressure reverses itself, so that increasing pressure beyond these limits causes more and more usable liquid to remain in the gas. Thus, under normal trap temperatures, the liquid content of gas separated from a given oil at, say 1500 pounds pressure, will be higher than the content of the gas separated from the same oil at the same temperature, but at, say 600 pound trap pressure. This effect varies with the composition of the gas/oil mixture, and with the temperature of separation. So far there is no exact method for calculating the magnitude of the effect, even if the gas/oil composition is accurately known; hence, it must be determined by tests. An excellent article on this subject was published in the September, 1937, issue of Industrial and Engineering Chemistry, by D. L. Katz, and K. H. Hachmuth.

In the example under discussion, the oil from the primary separation would be run to a secondary separator at lower pressure, where most of the solution gas would be removed and processed through the gasoline plant. The pressure of this secondary separation might be determined by requirements for delivery to a pipeline for sale; otherwise, it would be selected to give a satisfactory and economical operating pressure for the plant, in the range of, say 150 to 500 pounds. It might then be necessary to pass the oil through one or two additional separators at

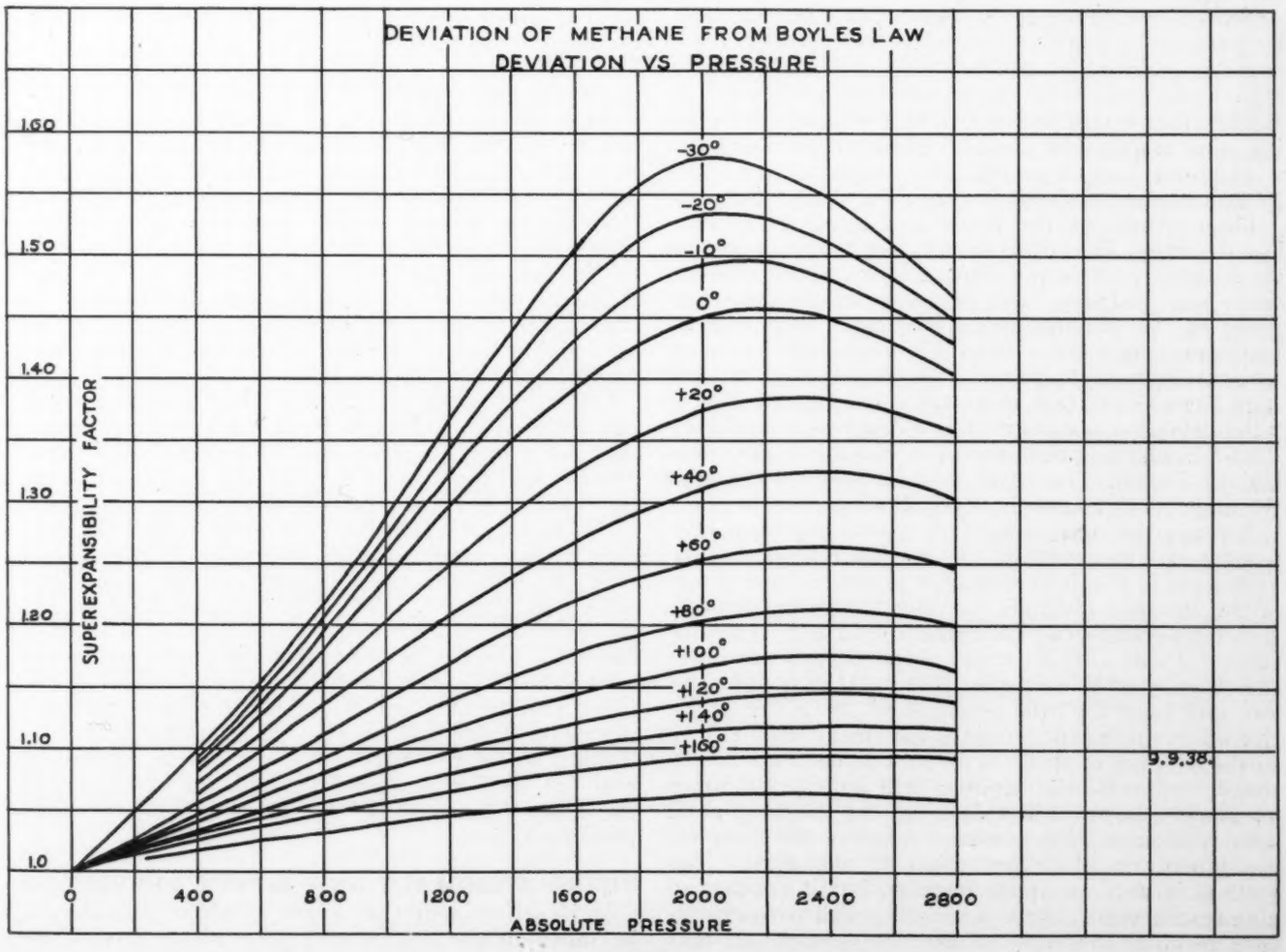

FIGURE 2

successively lower pressures, in order to reduce the gas content and vapor pressure of the oil to a point sufficiently low to prevent unreasonable storage and handling losses. The vapors from these low-pressure stages would, of course, be recovered for extraction of gasoline. As a final complication, particularly with high-gravity oils, it may be necessary to pass the crude through a stabilizer to remove excess butane and propane, in order to give it a satisfactory vapor pressure.

Depending upon local market and producing conditions, the scheme of production just outlined obviously can be rearranged in many ways. For instance, if the natural gasoline content of the gas is low, and the crude gravity also low, the viscosity-cutting effect secured by returning wet gas to the formation may be more valuable than the gasoline which might be produced. In such a case the gas would simply be pumped back without treatment. Here, also, the principle of separating as much gas as possible at the highest pressure possible will lead to the cheapest installation.

COMPRESSOR HORSEPOWER REQUIREMENTS

At pressures in excess of about 600 pounds per square inch the so-called "Super-Compressibility" or Boyle's law deviation begins to become noticeable in its effect on compressor horsepower; this effect reaches a maximum at pressures around 2500 pounds per square inch, and then decreases at higher pressures until it practically disappears at pressures in the neighborhood of 4000 pounds. The effect of the deviation is to increase the amount of gas which can be pumped by a given amount of horsepower, since a given quantity of gas occupies less space at the higher pressures than the uncorrected application of Boyle's law would indicate. Exact methods of figuring the magnitude of this effect have not been worked out, and no practical information from high-pressure indicator cards is available yet.

Figure 2 shows the theoretical effect of Boyle's law deviation at various temperatures and pressures up to 2800 pounds per square inch, when working with pure methane. The deviation of all the other gases of the paraffin series is greater than that of methane, hence the data of Figure 2 may be taken to conservatively represent the horsepower advantage due to deviation with any usual gas. In Figure 2 the deviation is presented as a "Super-expansibility Factor", which is the inverse of the Super-compressibility Factor. The chart may be used to estimate the effect of deviation in the following manner:

Assume the compressor is to pump gas from 1200 pounds absolute with 80° F. suction temperature to 2400 pounds absolute discharge pressure. Use of one of the common methods for estimating the compression temperature rise indicates a discharge temperature of about 180° F. under these conditions. From the chart, the "Y" factor is 1.138 for 1200 pounds and 80°, and 1.062 for 2400 pounds and 180°. The deviation effect during the compression stroke will be close to the average of these figures, or 1.100. This means that a compressor horsepower will pump 1.100 times as much gas through this range of pressure as it would through a low-pressure range of the same ratio, where the deviation effect is negligible. This method is only an approximation, but it appears to give results which agree reasonably well with experience to date. It should perhaps be pointed out that the effect of deviation just discussed is in the nature of a correction to be applied to the usual methods for figuring compressor horsepower within pressure ranges wherein deviation is not appreciable; such methods are available in handbooks and in data published by the various compressor manufacturers.

TABLE 1
Cost of Compression for a 2400 Horsepower Plant Compressing 10,000 M.C.F. per 24 Hours from 30 lb./sq. in. to 1500 lb./sq. in.

	Cost per 24 H.P. Hour
Operating Labor (3 men at $8.75 and 3 at $7.25 per day)	$0.0200
Lubricating Oil at 40 cents per gallon	.0040
Water and Water Treatment	.0005
Lights	.0007
Fuel at 5 cents per 1,000 cubic feet	.0120
Repair and Maintenance Labor	.0070
Repair and Maintenance Materials	.0035
Miscellaneous Supplies	.0004
Auxiliary Pump Power	.0010
Total Cost per 24 H. P. hour, including Fuel at 5 cents per 1,000 cubic feet	$0.0491
Total Cost per 24 H. P. hour, excluding Fuel	.0371

HIGH-PRESSURE COMPRESSOR INSTALLATION AND OPERATING COSTS

Compressor-plant installation costs will, of course, vary over a considerable range according to the size of the installation, operating pressures, and types of auxiliary equipment used as determined by the expected life of the plant. Recent figures on several gas injection projects involving final discharge pressures ranging from 1200 pounds to 4700 pounds indicate that installed costs per horsepower will run from 10 percent to 20 percent higher than in plants where the maximum pressure is not over 500 or 600 pounds. For example, a recent 1500-horsepower plant designed to pump gas from 30 pounds to 250 pounds showed an installed cost of about $90 per horsepower: Another 2400-horsepower plant to pump from 1200 pounds to 3000 pounds cost practically $109 per horsepower. Both of these installations include an "indirect" or closed cooling system, employ angle-type compressor units, and are otherwise quite similar in general standards of construction. The increased cost of the high-pressure installation is caused chiefly by the greater cost of the high-pressure piping and valves, and of the forged-steel compressor cylinder construction.

Operating costs per installed horsepower should run little, if any, higher for a high-pressure plant than for a low. Experience with extreme high pressures is still too limited to yield any good figures on this point. A recent careful analysis of operating costs, based on extensive experience with low-pressure plants combined with what data is now available on high-pressure operation, yields the data shown in Table 1. The plant contains 2400 horsepower of machine capacity, and compresses 10,000,000 cubic feet per 24 hours from 30 pound gauge intake to 1500 pounds final discharge. Similar figures for a variety of plant sizes and pressures are presented in Table 2. The first two sets of figures in Table 2 show the effect of plant size on operating cost per MCF compressed through the same ratios; the other figures show the effect of various compression ratios.

PIPING STANDARDS AND SAFETY PROVISIONS

It is self-evident that every possible care should be taken in the design of piping systems, and the actual execution of the work, to guard against me-

chanical failure when dealing with gas at any pressure. This is particularly true when working with gas injection pressures, since in addition to the hazards from fire which surround any gas operation, terrific mechanical destruction may be produced by the gas itself. It is an interesting fact that so far the accident record of extreme high-pressure gas installation is clean, which simply indicates that with proper design and execution of the work, combined with careful operation, such installations need not present any unusual hazard. The following remarks cover miscellaneous points of design based on my own experience with high pressures.

For the general design and selection of pipe, flanges and fittings, the present American Standards Association piping code has proven perfectly satisfactory. I believe this code is perhaps over-conservative in requirements for pipe thickness, but this is a good fault.

We have found the grooved flanges with soft-iron ring gaskets very satisfactory for pressures up to 4700 pounds, which is the limit of our experience. Incidentally, the static test pressure on the piping system on this job after it was completed was 7200 pounds. In designing piping where these flanges are used, it should be kept in mind that a joint cannot be broken unless there is an end-play between flanges of about ½-inch to ¾-inch, depending on size, to permit dropping out the gasket ring.

Lubricated plug cocks have proven satisfactory as valves for high pressures; we ordinarily use the worm or spur-gear operated types for sizes above 4-inches.

Check valves should be installed in each compressor discharge branch, and in the main discharge line outside the plant area is practicable.

Expansion and contraction strains in the piping due to operating temperature changes should be carefully studied, and provisions made to take care of them without throwing undue strains on connections to the compressors. This applies particularly to the discharge piping, since the gas is ordinarily not cooled after compression. Strain relief requires rigid anchorages at certain points to prevent creeping, sliding anchorages at other points to permit expansion but prevent vibration, and bends or expansion loops spaced as required to prevent accumulated strains. Expansion of headers between machine centers can be cared for by making the branches long, or by forming vertical loops in them.

We favor the installation of all piping above ground, including field lines as far as possible. This is ordinarily done by supporting the pipe on substantial concrete piers, with heavy sliding or tight clamps to hold it down. Such construction is little, if any, more expensive than burying, and it eliminates the possibility of failure through external corrosion.

When installing vent connections from safety valves, bursting discs, or other high-pressure sources, the possible reaction forces at the vent opening must be provided for. A 3-inch vent, blowing 3000 pounds gas wide open, may exert a reaction force of over 21,000 pounds; obviously such a vent must be properly supported to withstand this force. If screwed vent valves of any kind are used, the vent piping on the discharge side of the valve must be arranged so that the reaction cannot possibly unscrew the valve from its mounting.

We have used electric arc welding with coated rod for all pipe welding as far as possible. The welds are laid in beads not over ⅛-inch thick, with thorough peening between beads. With such procedure it is usual to have the entire piping system pass the final hydrostatic test without a single weld leak.

TABLE 2

Compressor Plant Operating Costs

Plant Capacity B.H.P.	Plant Capacity Mcf/ Day	Number Compression Stages	Intake Pressure, Lbs./ Sq. In.	Discharge Pressure, Lbs./ Sq. In.	Compression Ratio R	COST OF COMPRESSION	
						Fuel at 0 Cents per Mcf	Fuel at 5 Cents per Mcf
1,200	10,000	2	400	3,000	7.26	0.400	0.544
1,500	10,500	1	400	3,000	7.26	0.475	0.647
1,200	9,000	2	400	4,000	9.68	0.445	0.605
1,200	11,400	1	460	2,500	5.29	0.362	0.492
2,400	10,500	2	30	1,500	33.70	0.765	1.041
1,200	9,000	2	150	1,500	9.18	0.440	0.600

On account of the extreme destruction which can result from failure of any part of the high-pressure plant piping system, special emergency shut-off arrangements should be provided. In one plant now under construction such a system is arranged so that all sources of gas can be cut off by operating any one of four small plug-cocks, which are placed at strategic points around the plant. Piston-operated plug cocks are installed outside the plant fence in both incoming and outgoing main lines. Opening any one of the four emergency control valves will simultaneously close both these main cocks, blow down the pressure on the piping within the plant through a 3-inch diaphragm valve, and shut down the engines. The emergency controls are located in the compressor house, the office, at the plant gate, and at a point some distance outside the fence.

HYDRATE FORMATION AT HIGH PRESSURES

It has long been known that natural gas components form loose chemical compounds or "hydrates" with water, which hydrates freeze into ice-like solids at temperatures above the freezing point of water; and that the freezing point of the hydrates rises with increasing pressure. The behavior of a typical gas in this respect has been given by Hammerschmidt in Industrial & Engineering Chemistry, Vol. 26, 1934, Page 851. Hammerschmidt's curve and formula have been checked many times by experience, and may be taken to apply with reasonable accuracy to any usual composition of natural gas. Within my own experience I have seen hydrates form and partially plug pipe lines under the following approximate conditions: 42° F. at 250 pounds gauge, 54° F. at 420 pounds gauge and 80° F. at 4000 pounds gauge. Thus there is real danger of hydrate formation at normal temperatures in lines handling gas for gas injection.

Hydrates form only if the gas is at least saturated with water vapor under the conditions of temperature and pressure prevailing, hence their formation can be prevented by dehydrating the gas. Under most circumstances this would be impractical, and the only feasible way of preventing their formation is to keep the pipe line temperature above the temperature of hydrate formation. Under California conditions the heat of compression will ordinarily take care of this. At the Tepetate plant it was necessary to insulate part of the return line in order to conserve the heat of compression. In extreme cases it might be necessary to apply heat to parts of the line remote from the plant. This could best be done with

a hot water or steam jacket on the line, in order to avoid danger of overheating the pipe.

EFFECT ON PLANT DESIGN

In considering a new plant, the tendency of the gas to become leaner and to increase in volume should be kept in mind. Since a long life can be expected, the operator would be justified in selecting a plant somewhat over-designed for immediate requirements, so as to have some reserve for gas-handling and oil-circulating capacity. In any event, the plant should be so planned as to permit future expansion of these facilities at a minimum of expense.

The question of what is the best plant operating pressure can be settled only through a careful study of all the conditions surrounding the production and marketing of both the oil and the gas. The most vital point is the relative value of the natural gasoline if left in the crude oil as compared with its value as a separate product. If this material has more value in the crude, higher final trap and gasoline plant operating pressures are indicated, and vice versa. Subject to this limitation, the higher the plant pressure the more economical the whole operation is likely to be, since raising the plant pressure obviously reduces the compressor horsepower required for returning the gas.

It is my opinion that gasoline plants operating in conjunction with gas injection will tend toward higher pressures than have been used, combined with stabilization of the crude to give it marketable specifications. In view of some recent work, I believe it is entirely practical to operate an absorption plant at pressures of at least 1200 pounds per square inch.

CONCLUSIONS

Gas-pressure maintenance or repressuring operations tend to improve the operating conditions of natural gasoline plants associated with them in the following ways:

(a) By greatly increasing the average operating life.

(b) By stabilizing the rate of natural gasoline production.

(c) By preventing waste of dry gas which may be eventually sold.

In view of the result already accomplished, it is felt that this general subject deserves the earnest attention and support of everyone interested in natural gasoline production.

In closing, I want to express my thanks to A. K. Hegeman of Clark Bros. Company and Jim Reed of The Cooper-Bessemer Corporation for information on cost and super-compressibility, and to C. R. Williams of Continental Oil Company, George Sowards of Ohio Oil Company, and T. A. Huber of Humble Oil & Refining Company for data on actual operating results.

Refinery Modernization

(*Continued on page 30*)

price information on all fuels be available for each plant at all times, and also that all fuel purchasing contracts be so written as to permit prompt changing from one fuel to another.

The matter of proper water treatment for use in steam generating work or for cooling purposes in other refining operations is an item which is catalogued along with a great number of other items which can be considered as auxiliary to the principal concern of the combustion engineer in oil refinery operations. He must also have a certain amount of chemical knowledge to select proper methods of treating water to prevent scale deposition on tubes.

The various proposals submitted by these firms, having been checked individually in the manner shown, the proposals are thoroughly reviewed by the entire group acting as a body and final selection is made of the construction company to do the work, the factors deciding being the reputation and demonstrated ability of the companies under consideration for delivering the quantity of apparatus specified, quality of finished products desired, and for the price proposed. From this point on, the contract is handled through the company's construction engineers, the various people involved as above mentioned being consulted from time to time as the job progresses.

The re-arrangement and tying in of auxiliary and other equipment involves considerable engineering work on the part of the company's own construction engineers. This involves the employment by the company of a corps of draughtsmen, designing engineers and field engineers who not only design and lay out, but also actually construct the auxiliary equipment. This group of engineers also follows through on the contract work, checking all drawings and specifications prior to starting actual work, as well as inspecting actual results in the field to make sure that the contract is properly fulfilled.

The engineers who handle this part of the work are required to use a broad scope of knowledge of refinery operation and engineering practices. The work that has to be handled includes the design, construction and performance of foundations; structures of all kinds; piping; pressure vessels; power transmissions and controls, both mechanical and electrical; measuring instruments and automatic controllers of all kinds; furnaces and refractories for them; heat transfer equipment; thermal insulation; telephone systems; water systems; and many other classes of equipment that cover nearly every phase of the engineering field. The volume of work handled by this group varies a great deal with the amount of construction work going on in the company. The "peaks" and "valleys" of this volume cause some variation in the number of employes involved in this work, but during the "valley" times an experienced skeleten force that is not too large for the every day requirements of six refineries is maintained. When the "peaks" occur this skeleton force is expanded to take care of the additional load.

All of these engineers, of necessity, to keep abreast of developments all along the line, must be and are active members of the different existing technical associations. Active participation in sub-committee work is essential, and this work provides most of the necessary personal contact with individuals in other organizations that permits of interchange of ideas and information.

Considerable care must be exercised in coordinating the activities and individual interest of each of these groups of engineers, to the end that a completed project represents the known ultimate in efficiency, economy and flexibility to meet, at lowest cost, the ever-changing demands on the refiner from the consuming public.

ADVANCES IN

Design *and* Operation *of* Compressor Plants

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THE importance of compressor plants in the oil and gas industry probably does not have to be pointed out to men in that industry. However, it is interesting to see how, as the industry has grown, the number of plants and units has increased, and what changes in them have taken place. In this paper we intend to review briefly compressor plants in general and compressor units in particular, showing advances in their design, operation, and maintenance, and the advantages and benefits of these improvements.

Table 1, compiled from data supplied through the courtesy of the leading manufacturers of engines and compressors, shows approximately the number of the different types sold in California in recent years. It will be seen that the units have been divided into three main groups: compressors belt-driven by separate engines, horizontal direct connected units, and vertical angle type; also that the trend of installations has been progressive through these groups. Assuming that most of the older units are still in use, we can see that the quantity of units is constantly increasing. It is almost inevitable that this quantity will continue to increase, due both to the discovery and development of new fields, and to declining pressures in the existing fields. These declining pressures probably will require more plants, not only to carry on field operations, but also for deliveries of gas from the fields, as the initial pressures become inadequate. Thus, it seems that compressor plants and the modern improvements we can make in them are due to become increasingly important. Their importance is shown also by the estimated value of the plants, shown in Table 1 to be a surprisingly large figure in total.

Up to about 1923 the main compressor units usually consisted of a compressor driven through a long belt by an ordinary "stationary engine." The engines were usually two-cylinder, two or four cycle, and generally operated at speeds of from 150 to 200 r.p.m., with strokes of 16 to 20 inches. These belt-driven units usually ranged in size from 100 to 175 horsepower, but there was some tendency to overrate them. Although it was possible to attain the rated BMEP in continuous operation, the general practice of the field operators was to maintain about 80 or 90 percent of the rated figure.

Many of these units are still in active service today, faithfully pumping millions of feet of gas, but their disadvantages were numerous. The long belt drives required much space and large buildings. They were expensive to buy, troublesome to maintain without slipping, difficult to keep clean and neat, and required bulky and awkward guard rails. The chance of a belt breaking was a constant danger to the men and equipment, as well as a threat of a shut-down of from one to several hours when most needed. The large belt wheels on both engine and compressor brought up the same objections of size, guard rails, and the difficulty and danger of keeping them clean. In addition to the belt wheel, the engine usually had a twin wheel on its opposite side, the two of them acting as flywheels, but also taking more space, guard rails, and power.

*Before the annual meeting, California Natural Gasoline Association, Los Angeles, California.

DIRECT-CONNECTED UNITS

The next units to come into general use, about 1923-25, were the direct-connected engines and compressors. In spite of considerable reluctance of some manufacturers to change to this type, due to their belief it would not be a practical or durable design, they all did change eventually. These units comprise the largest portion of horsepower in our California plants, and are still being sold, though not so frequently as in the past. These were made in both one- and two-cylinder, two- and four-cycle types, usually operated at speeds of from 150 to 200 r.p.m., with strokes of 20 to 24 inches, and covered a much wider range of horsepower. This type varied from a few one-cylinder 50-horsepower units up to about 250-horsepower in the single-acting twin units, and then on up to around 1000 horsepower in the double-acting twin tandem units. These machines brought the

TABLE 1

Survey Showing Approximate Number and Horsepower of Gas Compressors in California Oil Fields

Type of Unit	No. of Units	Total H. P.	Approx. Period Installed	Estimated Plant Values
A. Engine and Compressor, belt driven	931	141,500	1915 to 1925	$18,500,000
B. Horizontal, direct-connected	789	161,855	1925 to 1935	16,200,000
C. Vertical-Angle Type	200	46,965	1935 to date	3,400,000
Totals	1,920	350,320		$38,100,000

TABLE 2

Economic Results of Advance in Compressor Design

Type of Compressor	Power Unit	Engine Cycle	Average Unit Rated BHP	Rated BMEP	Normal Operating BMEP	Ultimate Operating BMEP	Relative Power Weight	Relative Foundation Required	Relative Relative Floor Space	Relative Unit Power-Cost	Relative Installation Cost per BHP
A—Belted	Horizontal or Vertical	4	160	74	63	70	275%	270%	580%	205%	200%
B—Belted	Horizontal	2	160	45	36	45			450*		
C—Direct Connected	Horizontal	4	170	66	66	72	230%	250%	260%	135%	145%
D—Direct Connected	Horizontal	2	165	43	45	55	255%	290%	270%	115%	140%
E—Direct Connected	Horizontal	2	250	55	55	65	175%	200%	175%	100%	110%
F—Angle Connected	Vertical	4	300	75	75	81	100%	100%	100%	100%	100%
G—Angle Connected	Vertical	2	300	60	60	72	110%				

* Idler equipped, with 11′ 6″ Shaft Centers.

advantages of compactness, freedom from belt troubles, and a much wider choice of sizes and horsepower. For these reasons they have been, for several years, practically the standard machines for compressor plants.

During this same period several improvements were made in the design of the two-cycle power cylinder. These were the perfection of the fuel injector or economizer, giving fuel consumption about equal to that of four-cycle units; scavenging air pressure and power was reduced about 30 percent while its effectiveness was increased; cylinder and piston cooling was improved to an extent making it possible to increase the cylinder bore from 16 to 17 inches and develop BMEP within about 10 percent of that common to similar four-cycle engines. These improvements enabled the manufacturers to offer a 250-horsepower unit on the frame formerly used for 165- to 170-horsepower engines, at about a 20 percent reduction in installed horsepower cost.

VERTICAL ANGLE TYPE

Recently a third type of unit has been developed, and is bidding for first choice in the newer plants. This is the vertical-angle type, in which the power cylinders are vertical or in a V form, and the compressor cylinders are horizontal, both operated from the same crankshaft throw by articulated connecting rods. These units have from two to eight power cylinders, either two- or four-cycle, and from one to four compressor cylinders. They vary in size from 75- to 800-horsepower, and operate at speeds of from 300 to 350 r.p.m., but with piston speeds remaining within 11 to 12 feet per second. These units brought the advantages of further compactness, lighter weight, and thus greater ease in moving when necessary, lower cost, and greater economy in plant design. They take only about half the floor space of the horizontal units, and since they have only one small flywheel which can be completely enclosed, and their piping is more centralized, they can be run in a double row in an ordinary size building, or lined up in a way to best meet the requirements of the individual plant.

Auxiliary power units have come in for their share of remodeling too. While they may not attract so much attention, nevertheless modernized units are available and often well worth investigating. In the old days it was usually customary to set up a couple of fair sized engines and drive all of the auxiliary equipment, such as water pumps, air compressors, generators, plant shop tools, etc., from them through an elaborate system of line shafts, belts, and pulleys. Sometimes this forest of belts, shafts, and all the necessary guard rails took up as much space as three or four main compressor units. Now, however, compact self-contained or direct-connected units of one type or another are available for all of these purposes. They vary from the one- or two-cylinder vertical moderate speed type to the four- and six-cylinder, and even V-8 heavy-duty automotive type; can be had in speeds of from 500 to 2500 r.p.m., and generally can be adapted to operate on either liquid or gas fuel. Their small, compact size and almost all enclosed, self-contained features, make possible their installation in much less space than before. They also are much neater in appearance, easier to clean around, and much safer to work around, due to the absence of the large flywheels, pulleys, and belts.

Miscellaneous auxiliary equipment also has been subject to much improvement over that used in the early plants. Water pumps in those days were commonly of the bronze-bushed, single-suction, fairly low-speed type. If their impellers became a little worn, their efficiency dropped down as low as 60 or 70 percent, and their output dropped correspondingly, sometimes resulting in cooling problems in the plant. Now, ball-bearing, double suction, enclosed impeller, high-speed pumps are available with efficiencies of between 80 to 90 percent. These can be direct connected to the modern high-speed power units, or belt driven by the other types.

Cooling towers have become pretty much standardized since the days of spray ponds and cooling towers with a wide variety of louver designs. Spray ponds are seldom seen in new plants, and the cooling towers have considerable uniformity in their appearance and design. The tower louvers, spray racks, water distributing and collecting systems have been much improved, resulting in better cooling and less wind loss. This reduced wind loss has been an advantage both in the quantity of water used and in lower maintenance around the plant, due to elimination of the corrosive spray. The old cooling coils, so often made of banks of ordinary 2-inch pipe, are now largely replaced by brass tube coils. These, with proper water distribution, not only give better cooling, but lower maintenance costs due to their corrosion resistance. Being much more compact for the same cooling capacity, and made in standard sizes, they permit more flexibility of arrangement, and easier removal from one location to another when necessary.

Mufflers are another item which have undergone considerable change since the days when the engines often were allowed to bark unmuffled into the open air, or perhaps were quieted a little by the steam resulting from the water injected for cooling the exhaust pipe. Mufflers then usually consisted of con-

crete vaults or pipes with slots, holes, or baffles, in arrangements as varied as the number of their designers. All of these, however, were more or less inefficient, and since nearly all of them used water, with its attendant troubles, they were expensive to operate and maintain, not only in themselves, but the spray and steam blowing over the plant caused higher maintenance cost all around.

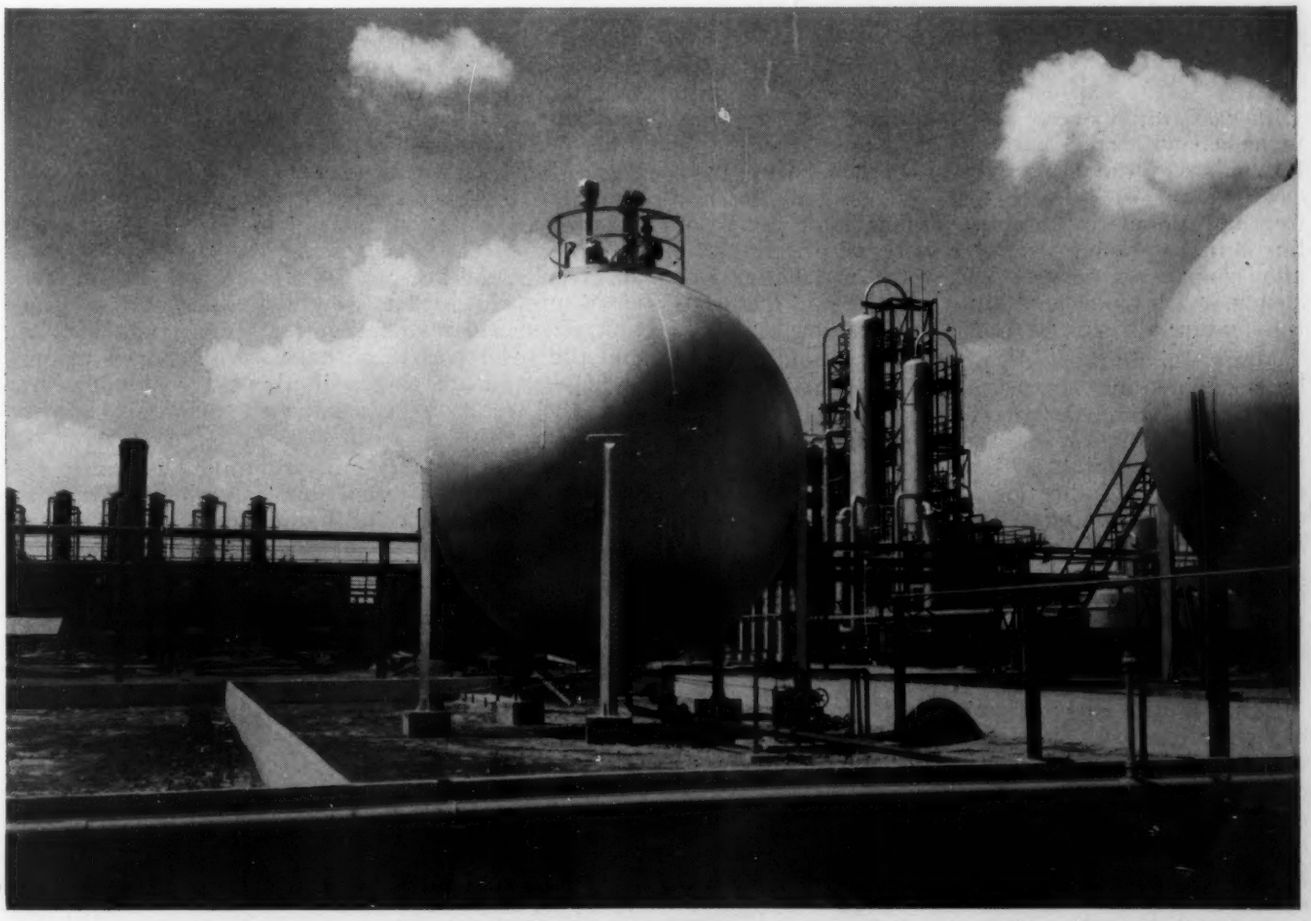
Practically the only more satisfactory muffler available both then and now almost without change has been a certain patented silencer. This has been available in different degrees of muffling and a variety of shapes and sizes. The other principal improvement in mufflers has been a patented air-cooled type. This was developed locally in Southern California, and is available in sizes for all types of engines. Using for cooling, instead of water, a strong blast of air sucked out of the engine room, it not only cools itself without cost, but also provides better engine room ventilation and eliminates the damaging spray and steam of the water-cooled types. These are now used widely in many plants, both here and in other parts of the country.

Improvements also have been made in the header and piping systems in compressor plants. Modern materials have contributed much to this advance. Sensitive pilot-controlled back-pressure regulators are now used sometimes in addition to pop valves on the plant discharge, giving more accurate, safer control, and eliminating the leakage often present in poorly maintained pop valves. Welding fittings, in all the variety now available, are a great improvement over the old cast iron, bolted fittings. They permit the extremely high pressures now coming into use and usually provide far more safety than the comparatively brittle cast iron fittings did in the past. They also are more compact and lighter in weight, thus permitting better design of the piping layout. In speaking of pressures, we may remember that we used to have trouble in getting cylinders for more than a few hundred pounds discharge. Now, however, cylinders are in use at 3500 to 4000 pounds pressure, and the manufacturers say they can be built up to 5000 pounds without trouble.

OPERATION AND MAINTENANCE

The foregoing covers the principal advances in equipment and design, so now let's talk briefly of operation and maintenance. Of the devices for improving and checking the operation of the engines and compressors, indicator probably comes first. Of course, it has been available for years, but it is perhaps better known and more widely used and understood now. More recent developments are the neon timing indicators and the exhaust gas analyzers. The first permits accurate ignition timing and the second, accurate fuel mixture analysis, both under actual operating conditions, thus enabling the best adjustment of these two vital factors.

Another device or practice perhaps used more widely now than in the past is that of load control with variable clearance. Many of the new compressor



Hortonsphere at Gulf Refining Company's refinery, Port Arthur, Texas, of 1000 barrels capacity designed for operation at 250 pounds pressure. This is one of the first units of this type installed for such high pressure work.

cylinders have this feature built in, or much the same effect can be secured on many of the older cylinders by the addition of outside clearance bottles. In this way the same cylinders can be used to cover a wide range of intake or discharge pressures, thus securing almost constant load, or at other times eliminating the purchase of new cylinders for a slightly different pressure range.

In the way of maintenance, there are several ideas whereby we can modernize and improve our old units. Starting with the oldest type—the long belt drive, we remember that later the spacing between engine and compressor was often shortened and an idler pulley added. This saved a great deal of space, but the idler was a nuisance, and the reverse bend in the belt caused more wear and tear on it. So the idea was tried of doing away with the idler and using a tight belt on the same short centers. With the usual large wheels and the belt maintained clean and in good condition, operation was found to be successful, and now quite a number of units are operating satisfactorily that way. The result has been a considerable reduction in space and in the first cost and maintenance of the belts.

A trouble sometimes found in these old engines with a heavy fly-wheel on both ends of a double-throw crankshaft was that of frequent and often disastrous breaking of the crankshafts. The idea that excessive torque stresses might be due to the inertia of these heavy wheels was thought of, so the wheel on one end was removed, leaving only the belt wheel on the other end. It was found that the engine operated very satisfactorily, so this change was tried on quite a few units. To my knowledge, broken crankshafts have since then become practically a thing of the past on these engines.

Most of the earliest 4-cycle units were supplied with cast iron valves. Later on most of these were furnished with steel valves, giving much better life. Replacing of the old valves as they burn out now can be done easily with steel valves, bringing this item up to modern practice. Another point along this line is that of facing the valve seats with special hard alloys, again to provide longer life and better efficiency. With modern welding practice and materials this feature also can be added to old units.

Many old units used fairly wide piston rings in both engine and compressor. Admitting that this question of ring design is still somewhat controversial, we do know also that several operators have found marked success with much narrower rings than formerly used. Indications are that their use may contribute materially to the reduction of rings and cylinder maintenance costs. In this connection the practice of honing cylinders after reboring also has been found to be well worth the cost in many cases. Prolonged life of rings, pistons, and cylinders in these cases has more than offset the additional cost of the honing job.

Many of the early engines used oscillating magnetos for ignition. The prevailing practice now is to use rotary magnetos, even on the horizontal direct-connected units, and obviously on the higher-speed, multi-cylinder units. In many cases when the old oscillating magnetos needed a major overhaul they have been replaced with the newer rotating type instead. This usually can be done without serious rebuilding of the unit, and the result is more accurate, better, and modern ignition.

In the early two-cycle engines the fuel was mixed with the incoming air before compression. Due to the fact, however, that this mixture also did the scavenging, there naturally was a certain amount of fuel lost in this process. To overcome this loss, the principle of injecting the fuel at about 15 pounds pressure in the head of the cylinder just as the scavenging ended was perfected. Fuel economy practically equal to that of four-cycle units was then possible, and most of the later two-cycle units were so equipped. Fuel injector type heads and accessories were then made available for many of the older engines, so that when it became necessary to scrap old broken heads they could, at some additional cost, be replaced with the new type. Their fuel economy then became comparable with the newer units, and they secured the added improvement of the more durable steel heads at the same time.

Forced-feed lubrication of reciprocating parts is an item which is probably much more common in modern units than in the old ones. As everyone knows, lubrication is subject to much variation and controversy, so that the advantages of adding forced feed lubrication to old units perhaps are best decided for each individual case.

Another device for securing safer and better maintenance is that for testing metal for fractures. Formerly this was done almost entirely by visual observation with whiting. Now a device for finding fractures magnetically is available, making possible the detection of flaws invisible under the old methods.

Apparent cost trends of modern plants compared with old ones are shown quite clearly in Table 2, along with considerable other data as to horsepower ranges, etc., of the various types of units. This table was compiled by the Compressor Committee from work initiated by Lyman Scheel, well known for his other work for the association. Since the new vertical-angle type compressors have not been out long enough to obtain the amount of operating and maintenance cost data that is available for the other types of units, positive answers to these questions cannot be given at the present time. However, certain facts as to unit cost, space, weight, building and foundation sizes ,and installation costs are available now, and the results of these have been reduced to percentages and are shown in this table. These show that the trend to reduced costs definitely follows the newer units.

The cost of moving units from one location to another is also in favor of the new style units. Being so much more compact and lighter in weight, they can often be moved without the slow and expensive dismantling and re-assembling usually necessary with the old larger types. Also, the cost of new foundations and buildings, and the loss of investment in the abandoned ones, is less for these units.

The expected life, depreciation, and obsolescence of these new types still remain to be seen, but these factors presumably should not differ greatly from the old units. Since some of the old timers are still running after 20 or 30 years, obsolete as they may be, these new ones should last quite a while. Obsolescence, in these rapidly changing times, remains to be seen, but even now experiments are being made on rotary type direct-connected engines and compressors. Whether these, or some still different type, will be the units of the future, only time will tell.

Moderate Refinery Activity Needed Until Spring

L. J. LOGAN

THE oil industry has ample justification for looking forward cheerfully into 1939. For as the new year begins to unfold, it is indicated that general business conditions will be good at least through the initial six months and quite possibly for two years or so. And when business in general prospers, the oil industry nearly always does well, if not better than most other industries.

Almost certainly, the oil industry will do larger volumes of business in 1939 than in 1938, as greater consumption of oil is indicated; and there is promise that the business volumes may somewhat exceed those of 1937 and thus set new all-time records.

NEW RECORDS OF DEMAND PROMISED

Domestic demand for gasoline in 1938 was only about 1 percent smaller than in 1937 and exports were higher. Therefore, total gasoline demand was up slightly in 1938, establishing a new all-time record. For 1939 a further increase of around 4 percent in gasoline demand, to another new peak, is indicated, by taking into consideration the anticipated brisk pick-up in sales of new automobiles, trucks and tractors.

Some other refined products also were in slightly larger demand in 1938 than in 1937, including kerosene, light fuel oils, and asphalt. And those products all may be expected to come into even wider use in 1939. Installations of domestic oil burners for heating probably will be unusually heavy in 1939, because of steadily increasing home building, and light fuel oil consumption consequently will be materially stimulated. Similarly, the construction work will result in good demand for asphalt.

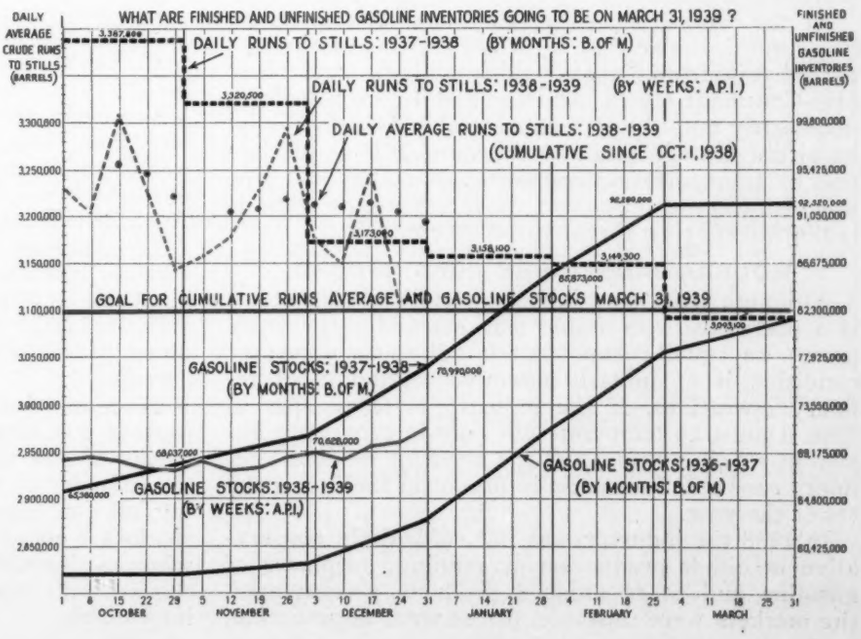
Despite increases in domestic demand for the above mentioned products and gains in exports of both crude and refined oils, the total demand for United States oils in 1938 probably failed by a little to equal that in 1937. And largely responsible was the lagging of domestic demand for heavy fuel oils and industrial lubricants. The domestic requirements for residual fuel oils were 13 percent smaller in the first 10 months of 1938 than in the corresponding period of 1937, and a similar decrease of 10.6 percent was recorded for lubricants. Declines for wax and coke were 4.8 and 7.1 percent respectively.

Up to now there has not been any material improvement in demand for the heavier oils. But the business recovery and increasing industrial production are to some extent stimulating consumption of those oils, and more definite gains are in prospect for 1939. Similarly, the generally expected further increases of business and industrial activity promise to cause improvement of demand for industrial lubricants.

SUPPLY MAY STAY WITHIN DEMAND

While the oil industry outlook is distinctly rosy from the standpoint of demand, it is promising also with regard to supply, which must be held reasonably in balance with demand, if the oil markets and prices are to be favorable and conducive to profitable operations. Control of supply promises to be fairly satisfactory in coming months at both wells and refineries.

Regulation of crude oil production was effective as the new year dawned, and a continuation of strict



curtailment through the whole first quarter of the year was promised, as the Texas Railroad Commission had set an example in temperance for other states to follow by ordering extension of Saturday and Sunday shutdowns of Texas fields until the end of March.

Oklahoma, Kansas, New Mexico and Louisiana in recent months have been cooperating well with Texas in controlling crude production, and those states can be fairly well depended upon to continue to do their shares toward holding national production in balance with market requirements.

Furthermore, California at the turn of the year, as if making and immediately executing a constructive resolution, suddenly eliminated most of its overproduction, having cut output down roughly from 670,000 to 610,000 barrels daily. Production had been too high throughout 1938, oil was going into storage, and the long established crude and refined oil prices were in serious jeopardy, when the California producers finally got together late in December and made voluntary proration work, thereby bolstering the Pacific Coast markets and indirectly those east of the Rockies.

ILLINOIS IS MOST SERIOUS PROBLEM

The one important state that is still a serious problem in crude control is flush and feverish Illinois, which belongs to the Interstate Oil Compact but which does not have or consumingly desire state proration. Illinois is a remaining frontier of rugged individualism in the oil business, and so far, proration is being served only straight—by the pipe lines—without being tempered by the whereases of state proration orders. There is some anxiety about the possible damage that Illinois may do, but facts do not justify too much worrying. The state's production has climbed above 100,000 barrels daily, and the output from the present fields is expected to reach 150,000 barrels daily in 1939, while new fields not yet opened may push the production still higher. However, these figures are not tremendous when written alongside the national demand of about 3,300,000 barrels of crude oil each day. Illinois might consistently produce 150,000 barrels a day and still fail by a little to satisfy its own consumption requirements.

At the worst, therefore, Illinois is not likely to cause more trouble than a further shifting of markets to that state from Kansas, Oklahoma, and some other Mid-Continent states. And meanwhile, such shifting necessarily must be to a considerable extent orderly, by virtue of the limits drawn around Illinois production by transportation and storage facilities and pipe line proration of purchases. So far, therefore, Illinois is not a terrifying threat to crude control.

MODERATE REFINERY RUNS NEEDED

Although strict curtailment of crude oil production is a prerequisite to stable markets and satisfactory prices, an equally important if not more necessary condition is a similarly effective regulation of refinery operations. If the industry is to prosper in 1939 it must be temperate not only in producing but also in refining crude, and the need for moderate refinery runs will be especially urgent in the first quarter of the year.

In 1938 the industry was not sufficiently conservative in either production or refining, surpluses of gasoline and other finished products accumulated, the markets were unstable, prices were unprofitable, and earnings suffered, despite comparatively good volumes of business.

In 1939 similar results might occur if the excesses should be repeated.

INDUSTRY NOW CAUTIOUS REGARDING STOCKS

However, with the disappointing record of 1938 fresh in memory, the industry currently is on guard against excessive inventories of gasoline and other products. And there are fair prospects that the stocks of gasoline may be kept from rising materially above the indicated economic level between now and March 31, when the usual increasing demand of spring may be expected to start withdrawals from storage.

FAIR SUCCESS IN HOLDING DOWN RUNS

It has been estimated that the maintenance of crude oil runs to refinery stills at a cumulative daily average level of 3,100,000 barrels for the whole fall-winter season, that is from October 1 to March 31, would result in an economically desirable inventory of approximately 82,300,000 barrels of gasoline on March 31; that quantity having been indicated as adequate for fulfilling the reasonably expected market requirements in the heavy consuming season of 1939.

So far, the industry has had fair but sometimes interrupted success in holding down refinery runs, and the fall-winter cumulative runs had averaged 3,202,500 barrels daily through December 24. It is apparent, therefore that the runs must be held down more strictly in January, February, and March, if the cumulative daily average for October-March is to be pulled down to the economically desirable level of 3,100,000 barrels. Specifically, daily average runs of approximately 3,010,000 barrels during January, February, and March will be required if the desired end is to be achieved.

CHART SHOWS RUNS AND STOCKS

On the accompanying chart the colored dots indicate the cumulative daily average refinery runs since October 1 through each successive week, and they therefore show the progress that has been made toward the desirable 3,100,000 barrel level of average daily runs for the whole six months' period, which appears on the chart as the horizontal colored line through the middle.

The broken colored curve shows the weekly fluctuations in crude runs, which were down sharply to 3,105,000 barrels daily in the week ended December 24.

The chart also shows, by means of the lower colored curve, how gasoline stocks have fluctuated each week. On December 24 they stood at 69,959,000 barrels, which was 6 percent lower than the supply held a year previously.

According to the calculations, the gasoline stocks will not rise above the horizontal, colored line, that is, above 82,300,000 barrels, by March 31, if the cumulative daily runs (the colored dots) are brought down by that time to the "goal line" level of 3,100,000 barrels.

In connection with refinery operations, an important consideration is the fact that present large stocks of gas and fuel oil make it unnecessary for the industry to maintain heavy runs to obtain heating oil for current demand. The gas and fuel oil stocks are about 23 percent larger than one year ago, whereas demand has not increased that much, and those stocks make any shortage of fuel oil supply improbable.